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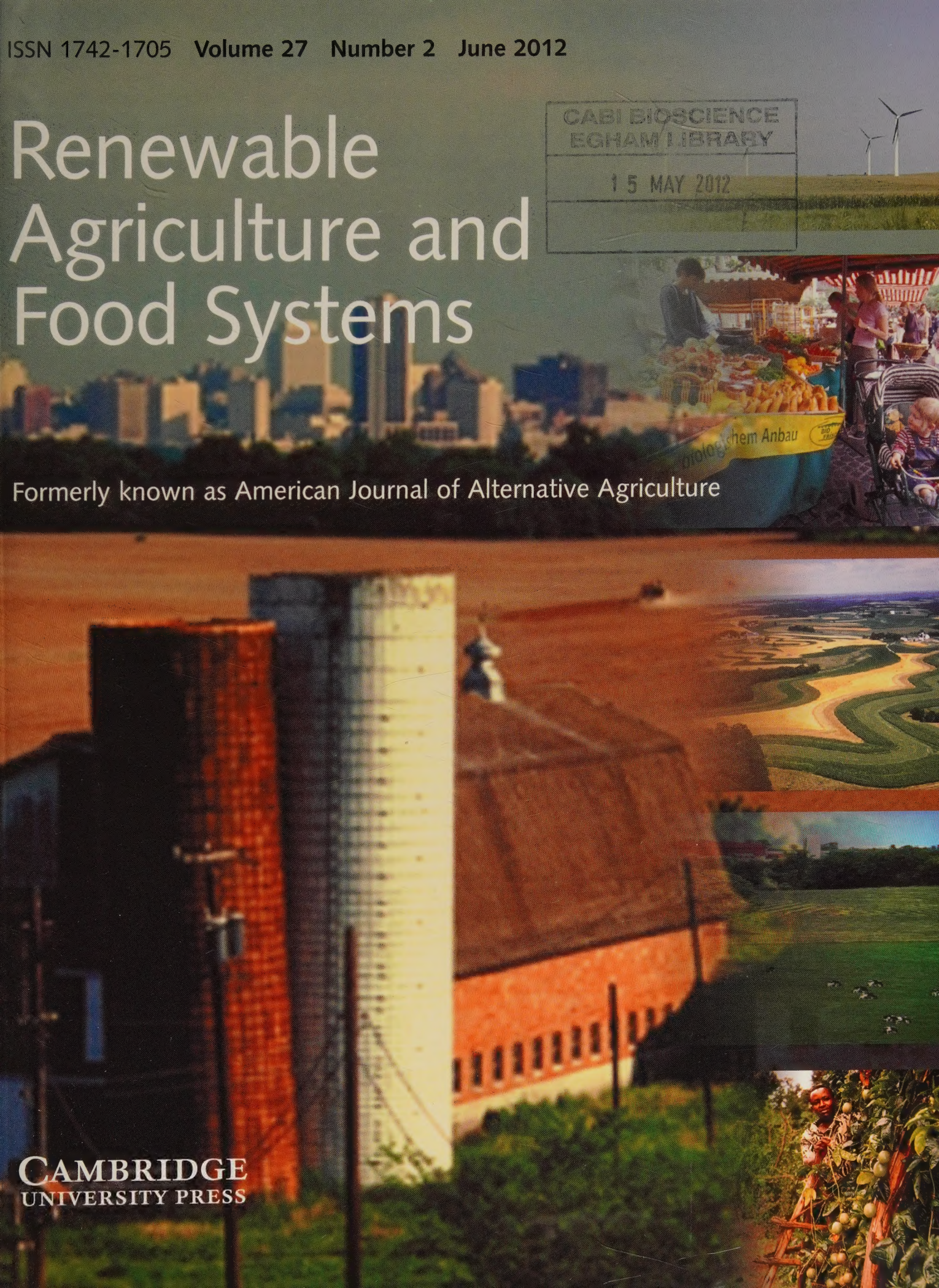

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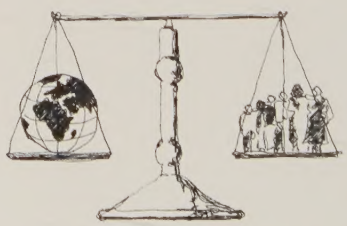

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Meeting the 'multi-' requirements in organic agriculture research: Successes, challenges and recommendations for multifunctional, multidisciplinary, participatory projects

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Abstract

Organic farming is one of the fastest growing agricultural sectors worldwide, and funds to support research and extension activities that address the needs of organic producers are becoming more widely available in the USA. Solutions to problems in ecologically complex systems, such as organic farming systems often exceed the expertise of individual investigators or single disciplines. Further, the complex nature of ecological and social interactions within systems-based agricultural research requires not only more emphasis on information exchange but also synthesis between multidisciplinary teams of academic researchers and organic farmers. Accordingly, federal grant agencies that support organic agriculture research increasingly require that projects encompass multiple academic disciplines, multiple functions (research, outreach, education), and the participation of stakeholders for the ultimate purpose of the integration of knowledge. Many researchers, educators and administrators at land grant universities (LGUs) remain inexperienced in multidisciplinary, multifunctional and participatory research. Using post-completion project interviews of the project investigators on an organic transition project, we identified eight factors that affected the integration of knowledge from a farmer advisory board and the conduct of our multidisciplinary, participatory organic transition project. The first five factors include shared values, balance in technical competence, institutional capacity for research, team capacity for problem solving and institutional resistance. The research team also identified three other factors that evoked confusion and divergence during the project, and include the ambiguity of power and control of knowledge, the proposed experimental plan and terms of team engagement. We considered participatory elements of the project according to Biggs' linear typology of participation, but found more appropriate Neef and Neubert's position that a linear scale of participatory approach is an inadequate framework for helping agricultural scientists to decide on whether and in which phases they want to, can and should incorporate participatory elements into their research projects. From these findings, we conclude with critical issues for academic research and extension teams to consider during the development and before conduct of these types of projects. We also offer recommendations for LGUs and other research institutions, and funding organizations, to facilitate multidisciplinary, multifunctional, participatory research.

Key words: participatory research, organic agriculture, multidisciplinary research, transdisciplinary research, evaluation metrics

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Introduction

Currently, organic agriculture is one of the fastest growing agricultural sectors worldwide. Organic farms are diverse in scale and in commodities produced in the USA[1]. Sustainable agriculture, which includes organic agriculture as one of its forms, emerged as part of a growing critique of the negative environmental consequences of modern farming methods[2]. For most of its history in the USA, sustainable and organic agriculture has been treated as an antiquated and unscientific means of production by academic and research institutions[3]. Because these movements were criticized and diverged from mainstream agriculture, and until relatively recently lacked government support that explicitly funded research, sustainable and organic practices received little attention from agricultural scientists in academic institutions[2,3]. Although research and education focused on sustainable and organic agriculture have increased, these movements have not been generally embraced by research institutions in the USA[2,4,5].

Organic agriculture in the USA started developing in the 1930s, but the concepts and concerns only became recognized and accommodated by research institutions in the 1980s[6,7]. During those times, termed 'the era of polarization' of agriculture into organic and non-organic sectors by Heckman[6], there was little effective communication between the organic-farming community and conventional agriculture community. Academic attitudes toward sustainable agriculture slowly began to change in the late 1970s with the publication of the *Report and Recommendations on Organic Farming*[8]. The report was produced for the express purpose of increasing communication between organic farmers and the US Department of Agriculture (USDA)[8]. The report compiled and interpreted scientific evidence on the yield, net returns and other performance indicators of organic farming in the USA and provided recommendations for research, education and public policy. Around the same time some advocates supported using the term 'sustainable agriculture' with the hope that it would invite respect for organic farming[9]. In 1985, the US Congress passed the Food Security Act, which included Subtitle C (The Agriculture Productivity Act), which provided for sustainable agriculture research. The Act established a competitive grants program in USDA, the Low-Input Sustainable Agriculture (LISA) in 1998 that focused on improving the scientific, educational and practical foundation of farming systems in harmony with nature.

LISA was the forerunner of today's Sustainable Agriculture Research and Education (SARE) program[9]. The LISA Program advocated the ecologically responsible use of all farm inputs. The primary goal of the LISA program (and the latter SARE program) was to develop and promote the adoption of farming and ranching systems that would meet the food and fiber needs of the present, while enhancing the ability of future generations to meet their needs and promoting quality of life for rural people and the rest of society. It did not advocate the elimination of synthetic chemical pesticides and fertilizers. LISA, and now, SARE, fund projects intended to increase the productivity and profit from farming systems that are less dependent on synthetic chemical inputs, and placed a high priority on projects that addressed real-world problems and included multiple disciplines and multiple institutions, including private organizations and farmers[9].

A divergence of sustainable agriculture and organic agriculture became more apparent with the exclusion of most synthetic pesticides and fertilizers as organic standards developed in the 1970s and 1980s[6,7]. The Federal Organic Foods Production Act of 1990, established national standards governing the marketing of organically produced products, assured consumers that organically produced products meet a consistent standard, and facilitated interstate commerce in both fresh and processed organic foods[10]. The Act conferred some level of authority on the organic movement, and thus began the era of accommodation for organic farming in the USA, followed by certification and labeling of products as USDA Certified Organic in 2002[3,6,10].

Since the implementation of the US National Organic Standards in 2002, academic interest in organic agriculture as a focus of research and education has increased[11], partly because of the growing availability of private and governmental funds to support these activities. A survey of the US Department of Agriculture's research database found that only 34 projects explicitly focused on organic systems or working methods, and described an experimental setting consistent with conditions found on organic farms[12]. These projects represented less than one-tenth of 1% of USDA's research portfolio, both numerically and fiscally. Lipson[12] concluded that the US national agricultural research system failed to recognize the potential of organic agriculture, explore it seriously, or help to improve the performance of organic farming systems. Through efforts such as those by Lipson[12] and organic advocacy groups, the USDA Organic Transition Initiative was authorized in 1998, and funded in 2001, with US$500,000 to support research on transition to organic[13]. In 2002, the US Congress passed legislation providing funding specifically for organic agriculture research. The USDA Organic Agriculture Research and Education Initiative mandated an appropriation of US$3 million per year for 5 years for competitive research grants. In 2010, the program had a total funding budget of US$19 million. Even though competitive federal funds to support organic research and extension in the USA are currently available, barriers to research and extension supporting organic agriculture still exist, largely due to agricultural professionals' lack of knowledge about, and experience with, organic agriculture[2,5,14–17].

Historically, research in non-organic production systems often focused on single-disciplinary, technology-based, short-term interventions as solutions to specific crop

production problems prevalent across broad geographical areas. In philosophy and practice, organic production is considered best approached in a holistic manner[18]. Indeed, the US legislation that supports organic certification demands this approach through the federal definition of organic agriculture and the requirement for an organic system production plan. Because of the prohibition of synthetic fertilizers and lack of prescriptive pest management guidelines and materials to address crop production problems in organic systems, research that focuses on a systems approach with a high amount of crop diversity is emerging.

The historical lack of support by the land grant universities (LGUs) and the Cooperative Extension Service for organic agriculture resulted in organic growers and non-governmental organizations (NGOs) developing their own production systems and methods for overcoming production constraints within the framework of organic requirements, by necessity and often at great cost[19–22]. Therefore, a significant level of expertise in addressing production problems in organic systems resides with innovative organic farmers and in NGOs, rather than predominantly with personnel in colleges of agriculture and governmental research organizations.

Solutions to problems in ecologically complex systems, such as organic agriculture production systems, are often not contained within traditional academic domains and, therefore, approaches to achieve robust solutions often exceed the expertise of individual investigators or single disciplines[22,23]. Management of systems for sustainability relies on a diverse and multifaceted knowledge system in which disciplinary boundaries are transgressed and techniques are continuously updated to reflect current understanding and needs[24]. This requires innovative approaches to problem solving that go beyond 'mode 1' knowledge production, which is traditionally the more common type of research in academic institutions—investigator-initiated and discipline-based, to 'mode 2' scientific knowledge production that is context-driven, real-world problem-focused and multidisciplinary[25].

More recently, several authors have considered transdisciplinarity as the appropriate approach to research in sustainable and organic agriculture. Transdisciplinarity is a research and knowledge production strategy that goes beyond traditional conceptions of scientific disciplines to integrate and synthesize many different disciplinary perspectives[24]. It implies that problem-solving strategies must be based on a close interaction between scientists and other actors to overcome one-dimensional and linear interconnection between science and society that are barriers to solving real-world problems[26,27]. Using the framework provided by Fleck, Aeberhard and Rist[26] examined the history of transdisciplinary co-production of knowledge in Swiss organic agriculture to illustrate that a process of collective cooperation is needed to generate solutions to problems in organic agricultural production and overcome social and historical contexts often neglected by science. Transdisciplinary research frameworks allow characterization of scientific as well as non-scientific actor categories, taking account of the interrelationship between the social context of interaction, the specific styles of perception and different forms of knowledge. For example, farmers emphasize experiential knowledge, while scientists focus on the scientific method and on conditions leading to success[26].

To achieve sustainable management requires co-production of knowledge through a process of collaborative learning between 'experts' and 'users.' This requires a shift from the view of knowledge as a 'thing' that can be unidirectionally transferred from expert to user to the view of knowledge as a 'process of relating' that involves negotiation of meaning among partners[28]. Warner[29] suggests that the formation of innovative multidisciplinary partnerships and a shift from a research–extension–diffusion model based on the knowledge of an expert to a social learning process that incorporates knowledge from both farmer and researcher are needed to address the relative lack of science-based production recommendations and the relative inexperience of the LGUs in organic agriculture. Further, the complex nature of ecological and social interactions within systems-based agricultural research requires more emphasis on information exchange and synthesis between multidisciplinary teams of academic researchers and farmers in organic agriculture, where in many instances farmers have developed their own information[22].

Funding organizations that support sustainable and organic agriculture research have recognized the historic lack of expertise in LGUs and the shortcomings of reductionist, single-disciplinary approaches for organic agriculture research, and accordingly, have increasingly required projects that encompass multiple academic disciplines in research and extension and, to varying degrees, the participation of stakeholders for the ultimate purpose of the integration of knowledge[30]. Participatory agricultural research and extension have a long history in developing countries[31], where there is growing acceptance and recognition of benefits for a participatory approach.[23,29,32–37]. The USDA SARE Program (http://www.sare.org/coreinfo/researchgrants.htm) provides 'competitive grants for sustainable agriculture research and education ... that usually involve scientists, producers and others in an interdisciplinary approach.' At the time of this writing, the USDA Organic Agriculture Research and Education Initiative (http://www.csrees.usda.gov/fo/fundview.cfm?fonum=1141) funded projects that integrate research, education and extension activities that address problems in organic agriculture, and require that, '... applicants will consult with organic producers and/or processors before developing project applications. Producers and/or processors should play an important role in developing project goals and objectives; in implementing the experimental or extension plan; and in evaluating and disseminating project results and outcomes ... There is

an expectation that a local and/or regional advisory panel will inform the program throughout its life, including the identification and prioritization of research, education and/or extension objectives.'

Even before these particular funding programs existed, concerns arose over the trend for 'participatory' to describe any approach which involves contact with farmers at any stage of research. True participatory research centers on people, power and praxis[38]. It is informed by and meets the needs of people who are empowered to create knowledge through an iterative process of critical reflection and action. Ideally, participatory research creates knowledge for action, contributes to the formation of organization and leads to change[38].

Biggs[39] provided a theoretical framework for levels of participation by creating a continuum distinguishing four modes of participation, with a concomitant range of not only power or control over project activities but the degree to which stakeholders contribute expertise or knowledge. In the contractual mode, stakeholders participate mainly as informants in a study or experiment that is designed, led and managed by scientists. This contractual mode maintains conventional power relationships in that researchers maintain control of the project. In the consultative mode, stakeholders are asked for their opinions and consulted by researchers before interventions are made with respect to the project. Stakeholders may have a 'voice' during the project, but overall institutional processes are not changed and control of the project remains with the researchers. In the collaborative mode, researchers and stakeholders work together on projects designed, initiated and managed by researchers. In contrast to the consultative mode, however, researchers and stakeholders work together as colleagues with different skills to offer, in a process of mutual learning. In the collaborative mode, there is greater focus on process than on results, and researchers serve as facilitators or catalysts for the production of knowledge by the stakeholders. This research mode is often characterized as being reflexive, flexible and iterative, in contrast to rigidly linear. The collegiate mode is similar to the collaborative mode, but ownership and responsibility for the project activities are equally distributed among the partners and decisions are made by agreement or consensus. In the collegiate mode, stakeholders are in control of the process.

Biggs'[39] framework of participation in agricultural research describes a linear typology of participatory research with an assumption of 'the more participation, the better'. The increasing demand for participatory approaches has seen a growth in methodologies that reflect different philosophical foundations to participatory research and consider the diversity and dynamics of agricultural research projects. However, a common element in these approaches is the major role of participants in shaping the research agenda[26,27,40,41].

When faced with the requirement for a multidisciplinary, multifunctional, participatory approach, agricultural researchers unfamiliar with or unskilled in applying these approaches may seek to fill the requirements in a variety of ways, especially if the expected level of participation by stakeholders or funders is not explicit. Stakeholders could even be involved at certain stages of a project without the project necessarily being participatory. For example, researchers could seek out stakeholders to fulfill pragmatic needs (i.e., the proposal will not be considered by the funding organization unless stakeholder involvement is demonstrated) or, stakeholders could be requested to provide supporting documentation (a letter agreeing that the research is needed) but not be invited to contribute on any other level. Stakeholders could also be invited so that the researcher could address political needs (e.g., conducting research that is traditionally in some other group's 'territory,' or demonstrating knowledge of particular underserved groups of stakeholders). In these examples, participation of stakeholders could result in a positive outcome, but 'participation' is merely a requirement in project design, rather than integrated as an approach and attitude, as a result creating a gap between rhetoric and reality[32,42].

A project can be considered fully participatory when stakeholders identify a problem, help design the research to address the problem, participate in the conduct of the project, evaluate the results or help disseminate knowledge created in the project, according to their own priorities. This process is in marked contrast to the way in which most agricultural research is conventionally practiced. As Biggs'[39] model suggests, power resides more with those who define the research problems, generate analyses, represent, own and act on the information that is sought. Full participation by stakeholders shifts the ownership of power, but at the same time, it can also raise personal, professional and political challenges that extend beyond the production of technical knowledge[32,42].

Many agricultural researchers and educators in LGUs are inexperienced in multidisciplinary, participatory research and unfamiliar with the historical and political concerns that led to requirements for this approach, not to mention the philosophical foundations of these approaches. While requirements to work across disciplines and with stakeholders are seemingly straightforward, few agricultural scientists in the USA are formally trained to work in or manage these types of projects. With some exceptions, for example[35], little published evidence exists about the factors that US agricultural researchers perceive as affecting the development and conduct of multidisciplinary, participatory research in organic agriculture systems. Therefore, our goal was to determine those factors that enhanced and detracted from the conduct of multidisciplinary, farmer-participatory research involving the transition to organic production and organic certification of land at a university research station. We conclude with considerations for academic research and extension teams, LGUs and other research institutions, and funding organizations, to facilitate the development of these types of projects.

Case Study: Organic Weed Management: Balancing Pest Management and Soil Quality in a Transitional System

The investigators on this project, members of disciplinary-based departments within a large LGU in the northeastern US, came together to develop an integrated research and extension project organized around the central theme of transition of a conventional crop production system to an organic production system (http://agsci.psu.edu/organic/research-and-extension/transition-to-organic).

The research team derived initial stakeholder input from two sources: from published needs assessments[16] and from organic producers at educational events held by NGOs that represent organic and sustainable agriculture. The university-based multidisciplinary team initiated the project through the successful development of a research proposal in 2003 to a USDA competitive grants program targeting integrated research, outreach and teaching in organic agriculture. A core of three faculty members from the Departments of Crop and Soil Sciences (with expertise in weed ecology and agronomy) and Entomology, with experience in working with organic farmers on production-related issues, had a strong interest in expanding research and education in the area of organic agriculture. These faculty members, as a result of initial discussions, selected a main research question and developed hypotheses with experimental systems consisting of four 'model' transition approaches.

The core faculty group recruited technical expertise from academic disciplines to achieve a whole system approach to address the research problem, inviting faculty from the Departments of Agricultural Economics, Crop and Soil Sciences, Horticulture, and Cooperative Extension to further develop the project, including the experimental design, analysis, outreach and evaluation components. Of the seven-member, university-based team, four members were junior and untenured, two were mid-career tenured faculty and one was a post-doctoral researcher. The six faculty members had been employed in the university for less than 5 years. All the investigators were either new to organic crop production research or, if experienced, had conducted it at other universities. They had not previously collaborated. Through an iterative discussion, a project emerged that contained multiple objectives, which were ambitious given the perceived need to address pent-up stakeholder demands for scientific, institutional and strategic needs related to organic agriculture in the northeastern US.

Representatives of sustainable and organic agriculture organizations participated on several levels. They provided input on the objectives and on the relevance of the work to their farmer members. They also served as core members of a stakeholder advisory board, the motivation being to build a better, more collaborative relationship with the stakeholder groups represented by these organizations, and by so doing, gain what theorists pinpoint as important, credibility with their farmer members[43].

The core team of advisors identified expert organic farmers to form a farmer advisory board for the project, resulting in a seven-member board consisting of the four core members (three representatives of non-governmental agencies and an agricultural educator, all organic farmers), three organic farmers considered leaders and innovators by the broader organic agriculture community, and a county-based extension educator. The advisory board agreed to contribute to the project by sharing their knowledge and experience at periodic project meetings, through individual consultations and at field days.

Personnel at the university's research station, two farm managers and a field technician, whose interest in the transition to organic production at the research station was very strong, acted as an extension of the advisory team. They participated in project activities and advisory board meetings over the duration of the project, providing insights on how best to accomplish recommendations as well as a check on the viability and practicality of recommendations. In general, they implemented the project on the ground, according to decisions made by the research team in consultation with the advisory board.

The objectives of our 4-year project were multiple, and encompassed research, education and outreach, and strategic goals. The campus-based faculty ('research team') defined the research objectives, which focused on comparing the efficacy of weed management approaches in the four model transition systems that varied in the frequency and intensity of inversion tillage, and the effects of these management approaches on soil quality indicators, populations of pest and beneficial organisms, crop productivity and economic indicators[44–47]. The education and outreach objectives were to gather and synthesize information on ecological principles critical to transition to organic production systems for incorporation into educational materials to support resident education and extension activities. The strategic objectives centered on building a conducive environment for research and education in organic agriculture in the future and included: (1) to build strong relationships within and between the academic faculty, the organic farming community, producers considering transition and regionally based organizations that represent organic and sustainable agriculture; (2) to establish certified organic land at the university's agricultural research center to serve as an ongoing resource for research, education and outreach activities in organic agriculture; and (3) to increase the awareness of university faculty, extension educators and students, and the general public that organic production is a valued and viable area for research and education in the university.

Overall, to achieve the ultimate goals of discovery and integration of knowledge, the project was 'integrated' on multiple levels. The faculty team worked to integrate the suggestions of the advisory board into research and extension activities. As defined by the USDA, it was integrated in that the objectives included research, outreach and educational activities. In a research systems sense, it

was integrated because the field experiment was an intermediately controlled and replicated hybrid of component and adaptive systems research. A whole-system research approach was taken, but the researchers were limited to testing a subset of management strategies based on the researchers' mechanistic and farmers' experiential knowledge[22].

Methodology of the Post-project Study

In light of the directive from the granting agency for a multidisciplinary team of investigators to incorporate the participation of a farmer advisory board, and the researchers' relative lack of experience and expertise in conducting participatory research, the research team decided near the end of the project to investigate self-reflexively, the array of factors that affected the carrying out of the directive[39]. We undertook a formative evaluation, one that focuses on the developmental or formative stages of a new activity or a project for the purpose of improving it when it is recreated[48]. This formative evaluation was undertaken toward the end of the funded project for the purpose of improving the participatory research process in upcoming studies[49]. Both the research team and the advisory board participated, the farmers at a later time. The results from the research team are presented here.

We chose a case study design because of its appropriateness for the study of procedures over time in applied settings[50], and for the context it creates for the team members to be considered collaborators in a process of information gathering[51], and for the study of a phenomenon within a context when the boundaries between the phenomenon and context is not clear[52]. The case study is not without its limitations, however. While it can lead to the identification and documentation of important details that could be used in future research, the lack of a control group and of the manipulation of variables preclude a precise measurement of the details[53]. Further, generalizations made from the findings in a case study are subject to further refinement and modification as research continues and thus in this study, we conclude with considerations for other teams, institutions and funding agencies.

We chose interviews as the data collection method because they provided: less respondent burden than a written survey, an important aspect given demanding schedules; more confidentiality than focus groups, an important consideration given the knowledge faculty had of one another; and more systematic information, as the same questions would be answered by everyone, unlike in a focus group setting. We chose to ask open-ended questions rather than quantitative questions, given our objective to identify the range of factors that affected the conduct of the project. Open-ended questions capture various meanings to common events, significant in this study due to the different role of each faculty member in the project[54]. Conversely, quantitative questions are asked only when researchers are confident in the range of possible answers. In the interviews, we asked what factors supported the accomplishments of the project's goals and what factors hindered or challenged this achievement. We integrated probes that asked for clarification of ideas and asked for examples to add validity and support for mere generalizations[54]. All of the faculty researchers and the post-doctoral scientist on the project team agreed to an interview. The participants, four men and three women, received the interview questions prior to the scheduled interview to enhance reflection and the duration of the interviews ranged from 1 to 2.5 h.

The interviewer, a faculty member with extensive international experience in training interviewers, brought the benefits of being an internal evaluator for the university, which as research suggests includes knowledge of the organization and a greater likelihood of the use of the findings[55]. Not being in the same discipline as other members of the research team nor part of the team that decided upon the design and implementation of the field research, the interviewer brought the benefit of being an external evaluator with more objectivity than an agricultural science team member could have brought. An interviewer can introduce bias however, and may in this study inhibit faculty from discussing, for instance, interpersonal relations and, as the research suggests, may have been more at ease writing such thoughts in a survey[49].

Data synthesis

Coding the interview data combined both emic (insider) and etic (outsider) views[56]. Initially the interviewer generated potential codes for anticipated responses and then coded the script for the first interview, adding codes for unanticipated ideas. The other interview scripts were coded in the same manner. Moving inductively to a more abstract level, the evaluator observed patterns among the codes, collapsing them into subcategories and again into larger categories (factors), using the criteria of internal homogeneity within categories and heterogeneity across categories. The interviewer then wrote a summary of each category or factor[57].

Results and Discussion

Eight factors emerged that affected the conduct of the multidisciplinary, multifunctional, farmer-advised project. Each of these eight factors is described in detail below. The first five factors are straightforward, reflecting the homogeneity in which the team perceived them. They include shared values, balance in technical competence, institutional capacity for research, capacity for problem solving and institutional resistance. The research team also identified three other factors that evoked confusion and divergence in how the team thought about them, a reflection of the nature of these factors; they are multidimensional and more complex. They include the ambiguity of power and control of knowledge, the proposed experimental plan and terms of team engagement.

These eight factors illustrate the dynamic nature of participatory research, as according to Biggs'[39] taxonomy of participatory research, the level of farmer participation and control in our project fell at different times within the consultative mode, with some activities in the collaborative mode and the collegiate mode. The research team frequently consulted the advisors for their opinions before implementing management practices in the research plots (consultative mode). Our advisory board meetings often included activities designed to facilitate co-production of knowledge through discussions (collaborative mode). For example, together we examined existing practical guides for organic grain production, and discussed the merits and drawbacks of each, as well as the advisors' desired format and content for an organic grain production guide, which the researchers, advisors and others are currently producing. On at least one occasion, the design of the experiment was altered according to the wishes of the advisory board, described in the case study (collegiate mode). Accordingly, our experiences support Neef and Neubert's[41] contention that typologies of participatory approaches that suggest different degrees of participation along a single scale are inadequate for agricultural scientists to decide on whether and in which phases they want to, can and should incorporate participatory elements into their research projects. The eight factors follow.

Shared values

Cooperative activities in research teams require that individuals in a team coordinate their joint intentions, deliberation and actions based on shared values[30]. During the proposal writing stage the research team demonstrated several shared values that supported the project over time. The first was that the team had a strong commitment to learning about organic agriculture, even though the general level of acceptance by the research team of organic production as an 'appropriate' or sound production system ranged from skepticism to enthusiastic advocacy. The team had the perception that institutional commitment to the area of organic agriculture was lacking. The second shared value among the researchers was that farmers in the state needed research-based information about transition to organic farming and that the farmers had not received this information from traditional sources, e.g., LGUs and Cooperative Extension. The third was the general belief that the university would benefit from development and access to certified organic land at the university's research farm by providing a place to conduct organic research over time, a venue to bring the farmers for their observation and feedback, to hold educational events and as a resource for experiential learning by resident students.

Balance in technical competence

The research team believed that it represented a diverse array of technical expertise with capacity to address the complex scientific hypotheses and multiple objectives outlined in the project proposal. They also believed that the advisory board reflected a diversity of experience with, and knowledge about, organic cropping systems that were appropriate and economically feasible for transition. Most importantly, the research team believed that the expertise of the farmer advisory board balanced that of their own, for they had less experience with organic systems and more experience with research on questions related to sustainable and conventional practices and within their own respective disciplines. Overall, the advisory board had significant influence on the specific agricultural practices employed within the framework of the experimental design, which was controlled by the researchers.

The research team also agreed that the project was facilitated by the technical competence of the research station farm personnel and their inclusion as advisors. Members of the farm personnel also operate their own conventional farms, and even though they were not experienced with organic production, were extraordinarily open to the concept of organic agriculture and dedicated to the success of the project. For example, they modified and cleaned farm machinery to comply with organic regulations, altered production practices, and assisted in the considerable amount of record-keeping required to accommodate organic certification standards. They also actively engaged in discussion with the organic farmers on the advisory board about their common farming practices, and cared deeply about implementing the recommendations from the advisory board and research team.

Institutional capacity for research

As employees of a large LGU, the team identified another factor that contributed to the project: they had access to field research facilities, equipment, communication systems and support personnel (some of whom periodically interacted with the farmer advisory board). Likewise, on-campus laboratory and computing facilities, infrastructure and general research administration at the university facilitated the project.

Problem-solving capacity

In general, the project team considered that their problem-solving capacity was enhanced by the ability of the faculty and farmer advisory board to respond to emerging issues related to the project over time. They also pointed to the farmer advisory board's readiness to actively engage in discussion, offering valuable advice especially on specific agricultural practices to the researchers, the research station farm personnel and, interestingly, to each other.

One influence on their problem-solving capacity that the researchers identified centered on the location of farmer advisory board meetings at the experimental plots. Because the farmers reside over a wide geographic area, and were engaged in their own farming operations, electronic and telephonic communication served as effective ways to maintain collaboration and obtain quick responses to

questions as they arose between advisory board meetings. Despite the general belief that problem solving benefited by the location of the meetings at the university, other faculty, at least in hindsight, wanted to meet them on their farms where it would 'show more respect' (i.e., demonstrate to the farmers that they were important to the project and that the researchers were willing to meet on the farmers' 'turf').

Institutional resistance

Despite the shared value among the research team and the advisory board about the need for organic research at the university's research farm, implementing the strategic objective of increasing awareness of this need presented challenges, testing how resolute the team would be. For example, some non-project faculty and extension educators consider organic production as a niche segment of agricultural production pursued by relatively few farmers on a limited acreage. The demand of some project staff and faculty to justify the research to these extension educators not involved in the project was unexpectedly stressful because immediate answers to questions posed about the research were not yet available. Additionally, the need to explain and justify the organic focus took time away from other project activities. However, one aspect of the project, having a farmer advisory board, seemed to legitimize the research with some extension educators, putting a crack in the wall of resistance early in the project. On the positive side, the difficulty of justifying the research to some non-project faculty and extension educators comprises a baseline with which to qualitatively measure resistance to organic research over time.

Of the previous five factors, shared values, balance in technical competence, institutional capacity for research, capacity for problem solving and institutional resistance, the first four led to the integration of knowledge. The fifth factor, institutional resistance, presented some challenges before integration of knowledge could take place.

Power and control of knowledge

The training of most scientists falls within the first-order tradition, which is the generation of knowledge, meaning and action controlled by an expert's perception of problems for the purpose of producing objective causal data. During their training, scientists are taught to consider themselves as objective and rational 'experts,' and as such are often hesitant to relinquish power and control to embrace knowledge from 'non-experts'[58]. The experience of a multidisciplinary, participatory team falls within second-order learning process in which the generation of knowledge, meaning and action is produced iteratively by the research team and advisory board through inter-subjective processes, and responsibility for engagement replaces objectivity in a whole-systems ethic[37,59]. Scientific training often does not include developing the skills required, or becoming familiar with the underlying theories that help guide and inform multidisciplinary, participatory processes.

Not surprisingly, therefore, ambiguity of power and control of knowledge among the faculty team and between faculty and the advisory board surfaced in the project. The ability to integrate farmer and scientific knowledge within the participatory process is difficult, even more so when knowledge is changing or disputed[32]. Confusion arose among the researchers about what questions were open for discussion with the advisory board, and if advisory board input was sought, how to evaluate the significance of the advisory board's information. At times some faculty questioned taking the advice of the farmer advisory board on every aspect of the project, suggesting that perhaps advice be limited to certain subjects. At other times some researchers were uncomfortable when the advisory board said 'We wouldn't do that' or 'That won't work,' not fully understanding whether they could avoid implementing the suggestions of the advisory board. Nor did some researchers understand how specific advice from other researchers would fit into the larger framework of the project 'so everyone could contribute' instead of feeling disenfranchised or 'left out.' No loss of ambiguity emerged a rare time or two when some researchers who disagreed with the advisory board members, sought to better educate them, an action perceived as inappropriate, if not demeaning, by other researchers, and contrary to the reason for the participation of the farmers.

Despite the ambiguity over the control of knowledge at times, some researchers accepted the views and ideas of the farmer advisory board with great respect for their experience in an area in which these researchers felt they had limited experience. Indeed, there was a perception by some researchers at times that the views of the farmers were sought out and more respected and valued by some researchers than the views of the other research team members on the project.

Upon reflection at the end of the project, some researchers felt there had been a need for a thorough discussion among the research team ahead of time about what questions were open for discussion with the advisory board, and if advisory board input was sought, how to evaluate the significance of the farmers' contributed information. Multidisciplinary, participatory projects also require scientists to shift from their role as an expert creating knowledge or change, to that of a facilitator, fostering conditions for team-organized knowledge[37] and these ideas should be part of the initial discussion of the project. Carolan[43] suggests that agricultural knowledge created by farmers does not necessarily deny the expertise of agricultural researchers, but that 'boundary work' goes into maintaining the fluid boundaries of systems imbued with unequal power relations (e.g., farmers versus researchers, research versus extension, applied versus basic research)[33,43]. How to maintain these fluid boundaries should also have been part of the early project discussions. Other researchers felt satisfied with the level of the review of the questions brought to the advisory group for input.

The proposed experimental plan: to adapt or not?

Disciplinary conventions influence appropriate methodology and its implications[32,58], and participatory research has its own methodology and its implications[60]. Martin and Sherington[32] point to the potential for conflict between farmer participants and researchers on a core issue when there is a perceived need of researchers for a more controlled comparative analysis of the performance of 'models' with wider applicability for the results. Indeed, the extent to which research team members believed that the original experimental plan should be adhered to, or adapted according to emerging conditions, influenced their openness to accept some farmer advice at times. Questions stemmed from an uncertainty about the relative importance of maintaining experimental comparisons which could be analyzed by standard statistical methods as opposed to responding to and making periodic changes to the experiment according to what the farmers would do based on conditions in the field. Continuous manipulation of experimental design based on input from farmers or advisory boards can make rigorous collection and analysis of data difficult and, as a result, researchers in other studies have often demanded that trial design and management must be agreed upon in advance[32].

In this project, there were no *a priori* guidelines developed as to how to decide on which methodological recommendations to accept and, therefore, not disappoint advisors or researchers, especially those with a stake in a recommendation. The lack of an explicit mechanism by which to balance the scientific goals of the experiment with the need to be responsive to farmer advisors had critical implications. For example, early in the field experiment, the farmer advisory board suggested a cropping sequence that differed from the original proposal, and the research team accepted their advice. This decision led to the greatly diminished participation by one researcher whose discipline was no longer represented in the experiment.

Among those who agreed with the more adaptive approach of adopting farmer advice about the experimental design, some reported that the decisions arrived at in interactions with the advisory board should be anchored in 'farming reality,' and not the analytical needs of research. Others thought decisions grounded in the applied had insufficient discussion of theoretical implications related to the need to adhere to standard scientific methods, maintain treatment differences to accomplish hypothesis testing, and the inability to analyze data resulting from a continuously changing experiment.

Terms of team engagement

Although the requirement by funding agencies and institutions for multidisciplinary, multifunctional, participatory approaches increases, there is a lack of specific guidance on how it should be accomplished over the life of the project. Similar to organic farmers, who were left 'on their own' to develop information and networks to share it[19–21], researchers, students and extension educators are often left 'on their own' to develop effective ways to interact across disciplines and with non-academic stakeholders[32].

Most of the challenges around teamwork focused on unvoiced expectations or uncertainties about researcher roles and engagement. Some researchers had a strong desire to have project team operational goals develop; however, some team members could not sustain their engagement in the project; had no such expectation due to a seeming lack of interest in engagement or lack of understanding about the expectations of multidisciplinary research teams; had confusion over how to contribute to the project as they perceived their role as 'limited' or 'sporadic'; or, had greater interest in competing priorities, for example, focusing on research and scholarship from which they could obtain publishable results related to their own discipline. Others, for whom the development of operational goals for the team was important, reported confusion about the level of commitment and responsibility that each faculty member should demonstrate for the development of the social cohesiveness, shared engagement and intellectual advancement of the team.

Failure to voice uncertainties or expectations was ascribed by researchers to a fear of looking stupid; appearing not to have read the materials in the proposal; being intimidated by study data presented from other disciplines; and feeling that the research team member did not need to know. Another plausible reason could be that scientists from different disciplines, or of different levels of seniority, who have not received the same scientific training, may not have the confidence or lack empowerment to question disciplinary subject 'experts'[58]. Additionally, dissent can produce a deterioration of the team's ability to function as a unit, although dissent can be a virtue if it helps the team to avoid groupthink, or provide a team with an opportunity to rethink its shared intentions, plans and values[30,61,62].

In hindsight, members of the research team, although accomplished scientists in their own disciplines, were unprepared for and unskilled at the 'social work' necessary to address researcher engagement, a premise of multidisciplinary, participatory research[32]. No explicit mechanisms were created to allow faculty discussion of uncertainties or expectations around researcher roles and engagement. During the preparation of the proposal, the research team focused on technical issues and it was only over time that the team began to raise these 'social process' concerns.

The final three factors, power and control of knowledge, the experimental plan: to adapt or not, and terms of team engagement, evoked a divergence in how the team thought about the processes in a multidisciplinary, participatory research project. The increasing awareness over time of these differences among the research team resulted in

discussions about the need to know ahead of time the expectations of this type of research and the need to establish guidelines ahead of time about the expectations of researcher engagement and for the integration of knowledge with a farmer advisory board. These results suggest that prior to initiating such a project consideration also needs to be given to the need for resources, time and a methodology for monitoring participation by all project members[32].

Considerations

Based on our experiences, we consider the following issues important for researchers embarking upon or improving current multidisciplinary, participatory projects, as well as for organizations and institutions who seek to foster these types of projects.

For academic research and extension teams

Multidisciplinary, participatory research is quite different from the more individualistic work for which most scientists are hired in research institutions. Issues, as described earlier, can become increasingly complex as the number and kinds of people and interactions increase, and management beyond organization of the technical aspects of the project needs to be accomplished. In multidisciplinary, participatory research, interactions tend to be peer-to-peer in contrast to hierarchical. This can be a new way of operation for researchers, and issues evolve out of this difference in operation that create both opportunities and challenges. We consider the following issues important for researchers to consider and discuss in the earliest stages of project development. Clearly, universities, teams or managers must commit resources, e.g., management time and funds, to support both technical and team operational activities.

Communication. Deliberate coordination and communication practices, meetings and retreats promote conflict resolution, the development of trust and synchronization of scientific work[63]. Establish open, clear and timely communication within the faculty team and between the faculty team and farmer participants or advisory boards early in the project. For example, at the initiation of a project, be specific in determining the desired frequency of communication, what information needs to be communicated and to whom information needs to be communicated. Develop formats, e.g., electronic, telephonic, face-to-face meetings, and routines, e.g., advance agendas with topics to be discussed and decisions to be made, to facilitate communication and group decision-making, to develop trust and to coordinate the synchronization of scientific work[63]. In our current multi-institution project, our geographically dispersed team has found that regular video-conferencing is more conducive than teleconferencing for clear communication when face-to-face meetings are not possible. The meeting facilitator requests agenda items from the whole group in advance of the meeting. The advisory board meetings are now designed to begin with an activity to elicit advisor discussion, rather than with researcher reports to the advisory board, giving the farmer-advisors the first voice. Topics of these discussions are gathered from the advisors ahead of the meeting. Routine research updates are handled through a periodic project newsletter and an annual report to help limit the amount of time that researchers are talking 'at' the advisors during face-to-face meetings.

Multidisciplinary, participatory research is dependent on respecting and understanding other team members and the external participants with whom researchers will work. The research team should determine to what degree the researchers realize that other team members and non-academic participants are knowledgeable and can create knowledge. There is a need to build an understanding of different 'research worlds' of each project participant. This requires a reflexive discussion on the focus and meaning conveyed by different research perspectives and the strengths and weaknesses of different research methods[18]. Team members trained in single disciplines must learn to appreciate differing perspectives and methods, may have different ideas about 'rigor' and may think of themselves (and their discipline) as 'more scientific' than others.

Roles and resources. Reach consensus on specific roles, responsibilities and levels of engagement of each team member and the project resources that will be committed to assist each team member. This includes the level of engagement of each team member in the development and conduct of project activities and products, and project management processes. For example, an explicit discussion about each team member's expectations for their own role and level of participation has helped team members avoid misunderstandings due to false expectations about each team member's level of participation. Establishing a supportive environment for open discussion of how the team will operate may seem superfluous to the technical research activities, but emphasizing the importance of the diverse knowledge held by the members of the whole team can foster greater participation and help the team function more efficiently[64].

Decision making. Develop a standard decision-making process and criteria that values and allows all team members to be consulted and participate. Those who feel less empowered in the process may need encouragement to provide their opinions, especially if there is disagreement within the group. The success of research may be improved by critical evaluation and change motivated by dissent rather than consensus[30,61,62,65]. Developing ways to accept dissent, for example, by aggregation of individual decisions that allow for the input of every participant, in addition to whole-team deliberations, may produce better decisions than deliberation to reach a consensus. For example, to provide an 'objective' mechanism to consistently and systematically approach suggested changes to the experiment, especially those that are

highly contested, our researcher and adviser team created a philosophy/guiding principles document for each experimental treatment. We have found that using this approach facilitates the ability of team members to come to consensus about adjustments to the experiment by allowing decision making to focus on the guiding principles rather than on individual team members. We have successfully used this process in subsequent multidisciplinary, participatory projects.

Determine and discuss how, by and for whom research is conceptualized and conducted[42]. Perceptions of degrees of participation may vary between the different team members—the research team needs to decide on the desired level of participation of non-academic external advisors based on the research question under investigation, and relative extent of farmer and research team knowledge and control over the research. Determine how researchers, advisory boards and farmers should manage their interaction. What is an acceptable level of interaction within the research team and with the advisory board? When interacting with the external advisory board, should an agenda be agreed upon by only researchers ahead of time? Should research items considered by the researchers as not open for discussion or change, be included on the agenda? What topics and at what level of detail should advice be sought?

Determine the extent to which control of decision making resides with farmers relative to the researchers. Under what conditions will scientific needs trump the advice of the advisory board? If substantive adjustments are made to the experiment, how will data be analyzed? When farmers make management decisions during the project, there is a risk that data collection plans may have to deal with continuous farmer manipulation of experimental plots, making rigorous collection and analysis of data difficult.

Considerations for LGUs and other research institutions

The recent surge in requirements for participatory methods by funding agencies may have exceeded the understanding of how participation can be institutionalized[66]. Integration of participatory methods into institutional contexts requires management innovations, skill development and new working procedures. Critical areas that need innovations include: building institutional linkages, maintaining communication, coordination and monitoring, and developing expertise in methodology for analysis and for evaluating project impacts. If institutions want their faculty to engage in and be competitive for funding that requires multidisciplinary, participatory approaches, some consideration needs to be given to providing training on team building, communication across disciplines, working with diverse groups and project planning. Other considerations include:

- Train undergraduate and graduate students and postdoctoral scientists to work in multidisciplinary teams. Go beyond simple assignment of team projects to students, to include theoretical materials and discussion about skills required to facilitate team work. Place these individuals in leadership roles for some aspects of projects. During the course of team projects, analyze and discuss what is and is not working and why.
- Provide incentives and rewards for scientists working across disciplines and for scientists working with farmers and other stakeholders, the core mission of LGUs. Budgetary practices at most LGUs often direct resources through discipline-based departments and functions (e.g., teaching, research and extension). In multidisciplinary projects, it can be difficult to account for a given researcher or instructor's salary and time. Multidisciplinary projects may face impediments because of a need of the faculty to serve the primary, department-based discipline. Multidisciplinary programs may meet resistance if they are perceived as competing for diminishing resources, e.g., funds and time. Untenured faculty know that when they seek promotion and tenure it is likely that some of the evaluators will lack a commitment to multidisciplinarity, and may fear that a commitment to multidisciplinary research will increase the risk of being denied tenure. Criteria should be developed to fairly evaluate multidisciplinary research in promotion and tenure decisions.
- Develop mechanisms for incorporating diverse stakeholder representation in institutional research planning and budgetary decisions, so that their needs and interests are appropriately represented and understood.

Considerations for funding organizations

There is a risk that the requirement for participatory approaches into formal agricultural research could result in the incorporation of the rhetoric of participatory research, without moving much beyond the contractual/consultative approaches. Agriculture-science-based research proposals are usually evaluated on evidence that the research is based on hypothesis testing, on technical details about experimental design and techniques, and the qualifications of researchers to successfully complete the proposed work. In programs that require integration of research and education/outreach, a plan for information dissemination and evaluation must be included.

- Programs that require multidisciplinary, participatory projects should require some information on how the team will function and interact with external advisors. Participatory research encompasses a broad range of levels of interaction with stakeholders that requires planning around 'social work' and team management issues. Calls for proposals should be explicit in expectations about the level of participation desired. It is relatively easy to use a rhetoric that promotes participation without indicating how different methodologies or participation 'modes' can be combined into the research, extension and evaluation.

- Innovations in funding programs to accommodate a more flexible, iterative and reflexive process (rather than linear and determined) need to be developed for programs requiring a participatory approach. Proposals often require specific timelines and budgets for project activities. Participatory research in the collaborative and collegial modes can be an unpredictable iterative process, not easily reconciled with time-limited research structure and funding. In general, there is little flexibility to substantially alter the experimental, outreach and evaluation plan in response to participant advice once funding has been awarded.
- Methods for analysis and evaluation of the effectiveness of participatory methods may differ from non-participatory projects. Methodologies need to be developed to analyze and assess results from iterative and flexible research and extension. Non-quantitative criteria for analysis and evaluation may be more appropriate for projects operating in a collegial participatory mode.
- Participatory research can be extended to include participatory outreach[33]. Often there is no requirement for describing participatory extension strategies or how they will be employed or evaluated[67].

Conclusion

Even though there are some limitations to our post-project reflective interview approach to understanding the experiences of a LGU-based research team with multidisciplinary, participatory research, we feel that much insight has been gained from which others may benefit. Through the post-project interview process, eight factors emerged and became validated when multiple members of the research team identified these factors. Some members of the team refrained from discussing certain issues that other members discussed, suggesting that there are issues in participatory research that are difficult to quantify or capture, supporting the urgent need for further investigations and development of methodology to best conduct multidisciplinary, participatory research. The level of participation was dynamic over the life of the project, and the project as a whole could not be easily categorized as belonging to any particular 'mode'[39,41].

Shared values and the capacity for problem solving helped to maintain team and project stability in the face of conflict in our study[65]. Overall, the research team found great professional and personal value in working with each other and with the farmer advisory team. We learned that a divergence of viewpoints among the research team can provide valuable opportunities to critically consider how to work most effectively with farmers and within our own teams in the future.

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Exploring the potential for sustainable weed control with integrated rice–fish culture for smallholder irrigated rice agriculture in the Maranhão Lowlands of Amazonia

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Abstract

Combining existing traditions of rice and of fish in an integrated rice–fish (IRF) culture is a promising strategy for sustainably increasing land productivity and diminishing the need for external inputs in smallholder agriculture of Amazonia. This study evaluates the potential of IRF for weed control in irrigated rice production. It was conducted from August 18 to December 5, 2008 in the Maranhão lowlands in the eastern periphery of Amazonia. We compared weed communities in four 3-year-old IRF and four adjacent 'conventional' irrigated rice (CIR) fields at 20 and 40 days after transplanting (DAT), at the mid-vegetative stage and at the onset of flowering, which served as an indicator of potential grain yield. Rice–fish fields contained differing mixtures of herbivore and omnivore fish species totaling 4000 fish per ha or 1.7 fish per m^3. Total weed density was reduced in the IRF system, particularly early in the season, the most critical stage for rice development. The integration of fish into irrigated rice cultivation affected weed species composition, with fish-weeding preferentially reducing monocotyledonous Cyperaceae, one of the more aggressive and problematic weed families in this region. Monocot weed density was negatively correlated with rice aboveground biomass at 40 DAT rice. Although floristic similarity between IRF and CIR fields was low, the impacts of IRF on weed species diversity and weed species richness were not significant. Thus, IRF was not associated with a simplification of the weed community. We conclude that fish-weeding may substitute for manual or chemical weeding in irrigated rice agriculture, an important consideration for resource-poor smallholder agriculture in environmentally sensitive riverine or delta areas of eastern Amazonia.

Key words: integrated systems, lowland rice, smallholder agriculture, sustainability, weeds

Introduction

The integration of fish into irrigated rice cultivation (integrated rice–fish (IRF) farming is an ancient production system that can be traced back to the year AD 220 in China[1], where it was developed as an intensification strategy for overpopulated rural areas. IRF subsequently expanded throughout Asia to India[2], Bangladesh[3,4], Vietnam[5,6], Thailand[7], Indonesia[8] and the Phillipines[9]. In Brazil, IRF commenced in the 1980s in the southern provinces[10], and is in its beginnings in the tropical north of Brazil, with pilot plots in Maranhão state established in 2006.

IRF farming is a promising management option especially for intensive smallholder agriculture, furnishing impressive gains in system productivity, resource use efficiency and ultimately in the sustainability of land use. In terms of per hectare productivity, irrigated rice grain production is associated with grain yields of up to $10\,Mg\,ha^{-1}$ [11]. Fish farming ranks among the highest-producing livestock systems with fish production frequently

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exceeding 550 kg ha^{-1} [12]. The integration of both components into one production system not only increases resource exploitation by niche partitioning but also creates a series of important synergistic interactions, notably plant and fish nutrition[13–15], pest control[6] and weed control.

Large areas of the Amazonian Atlantic coastline as well as those in other tropical regions are covered by marine hydromorphic alluvial soils. Such soils have a substantial potential to raise rice production via irrigated rice production, since they typically combine relatively elevated soil fertility with favorable hydrologic conditions and a flat terrain. This potential is turning into reality with a very rapid expansion of irrigated rice production in the study region. Large-scale (frequently>500 ha) semi-industrial operations predominate in the area and grain productivity averages 3 Mg ha^{-1}. These systems are based on direct-seeding, are highly mechanized and involve intensive use of chemical fertilizers and pesticides, a concern for environmentally sensitive riverine areas. Smallholder rice production is traditionally based on cultivation of upland rice via slash-and-burn shifting cultivation of *terra firme* (not inundated) lands, and productivity is very low (usually well below 400 kg ha^{-1}).

Smallholder irrigated-rice farming has been successfully promoted during the past decade in the study region, using low-density transplanting in continuously inundated fields, locally developed high-yielding varieties and chemical fertilizers. Rice productivity can be high (typically >7 Mg ha^{-1}), but the need for financial inputs for fertilizers and pesticides has proven to be an obstacle, especially for resource-poor farmers.

Fish is a traditional component in the culture of this region, but overfishing of the Mearim River has seriously reduced fish yields. The integration of rice and fish into a single and interacting unit constitutes a form of development that unifies existing traditions and knowledge. This system may well constitute an environmentally sustainable and much-needed pathway out of poverty for resource-poor riverine farmers of the region.

Weed populations are considered a critical issue in irrigated rice culture, as populations can increase after several years of repeated rice cultivation. Continuous flooding eliminates many, but not all, weed species, with the remaining weeds requiring manual or herbicidal control. Manual weed control is extremely labor intensive and is often associated with unsatisfactory labor productivity (i.e., economic returns as compared to local wages). Chemical weed control has therefore largely substituted manual weeding[16]. However, the often considerable financial costs are problematic in the context of smallholder agriculture, since they may cause the exclusion of resource-poor smallholder farmers from this production system. Perhaps even more seriously, chemical weed control bears potentially serious environmental risks, since areas of rice irrigation are typically located in hydrologically sensitive areas, allowing potential contamination of riverine ecosystems and water reservoirs.

Since weed species differ widely in their aggressivity and competitivity, there does not exist any universally applicable critical threshold of acceptable weed density or biomass above which irrigated rice grain production would be negatively affected[17,18].

Early stages of rice biomass can serve as indicators for future grain yields[19]. Weed pressure and weed control are governed by timing, density and composition, since weed species and functional groups differ widely in their aggressivity and weed control requirements[18].

This paper investigates the potential of IRF cultivation for weed control in irrigated rice production in 3-year-old pilot plots in the eastern periphery of Amazonia.

Materials and Methods

Study region

Research was conducted between August 18 and December 5, 2008 in the Embrapa research station of Arari county, located 165 km from the state capital of São Luis in the 'Maranhão lowlands', in the Mearim River delta (3°27′30″S, 44°46′00″W), 15 m above see level. Soils are fertile alluvial vertisol aquerts, with a high content of montmorilonite and illite. The climate is classified according to the Köppen system as sub-humid equatorial (*Aw*) with 1500–2000 mm of annual precipitation. Irrigated rice production takes place during the dry season (August–November) when the absence of rain and the proximity to the Mearim River guarantee control of water regime. During the rainy season, fields lie fallow or are extensively grazed by cattle or waterbuffalo.

Treatments

The four IRF fields constituted 3-year-old pilot plots, which we compared with four adjacent fields with conventional irrigated rice (CIR) cultivation. Preceding land-use history on all fields had been two decades of continuous irrigated rice production. Each field plot was 8.5 × 20 m.

Two thousand seven hundred and twenty 25-day-old rice transplants (cv EPAGRI 108) were planted into puddled fields, with a plant density of 16 plants m^{-2} on all fields (25 × 25 cm). CIR was kept inundated until the grain filling stage after which irrigation was intermittent, based on need. Both rice production systems received standard doses of chemical fertilizers: 10 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 30 kg ha^{-1} K_2O immediately before transplanting, and 45 kg ha^{-1} N as urea, split in two doses at 7 and 30 days after transplanting (DAT). Rice variety, water and transplant management as well as fertilizer rates were in accordance with high-intensity (i.e., 5–7 Mg ha^{-1} grain yields) smallholder irrigated-rice agriculture promoted during the past decade in the region. No pesticides were applied in any plot.

IRF fields contained by type 50% 'Tambacu' (female *Colossoma macropomum* Cuvier × male *Piaractus mesopotamicus* Holmberg) and 50% 'Thai tilapia' (*Oreochromis*

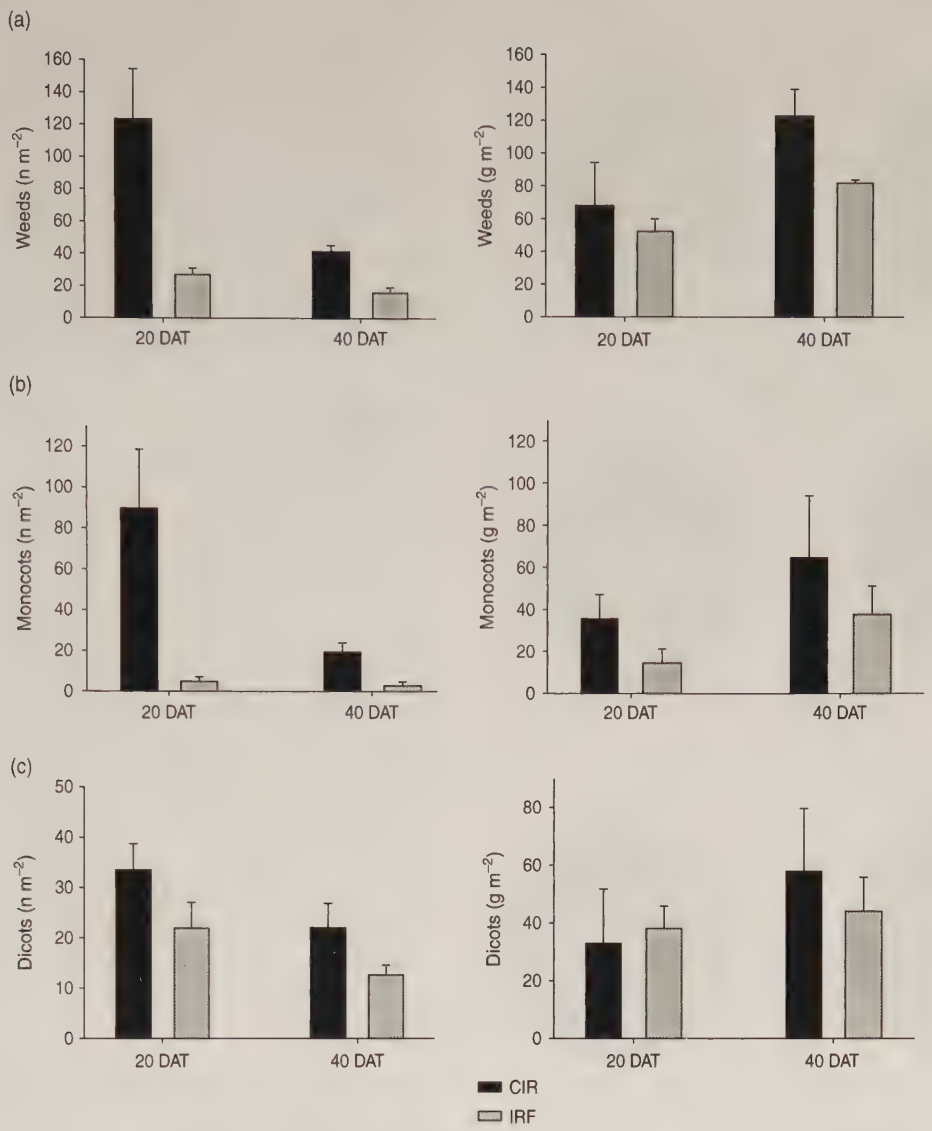

Figure 1. (a) Total weed density (left) and weed biomass (right) at 20 and 40 DAT in CIR and IRF management systems. (b) Monocot weed density (left) and biomass (right) at 20 and 40 DAT in CIR and IRF management. (c) Dicot density (left) and biomass (right) at 20 and 40 DAT in CIR and IRF management (means ± SE). Note scale differences between the three figures. All density data were ln-transformed for *t*-tests and ANOVAs.

niloticus L.) for a total of 4000 fish per ha or approximately 1.7 fish per m^3. The fish were released into the rice fields after attaining sufficient size, at 30 DAT. The previous 2 years of IRF had been conducted with the same rice density and with similar fish densities, with 'Tambacu' in the first year and a mixture of Hungarian carp (*Cyprinus carpio* L.) and grass carp (*Ctenopharyngodon idella* Valenciennes) in the second year. The IRF fields contained in addition to the irrigated rice field a fish sanctuary, comprising about 5% of the area required for initial fish raising (protection of juveniles against predators).

Measurements

We quantified weeds on two occasions, at 20 and 40 DAT, corresponding to two distinct stages of rice ontogenesis, mid-growth and the onset of flowering. These periods are considered critical for rice development[20–23]. Weed infestation was not quantified in the later stages of rice development (grain filling and maturation stages) when weeds presumably had less influence on rice. Weeds were quantified in three randomly distributed 1 m^2 samples per field, and field values were calculated as the means of these three samples.

We quantified weed density (number of plants m^{-2}), aboveground biomass and species composition in each plot. We also quantified rice biomass at 40 DAT in the same plots. Weed and rice dry weight biomass were determined after drying at 70°C in a forced circulation oven for 1 week. Weed species were identified in the field or in the herbarium of Maranhão State University. We subsequently calculated species richness, Shannon–Weaver (H′) and

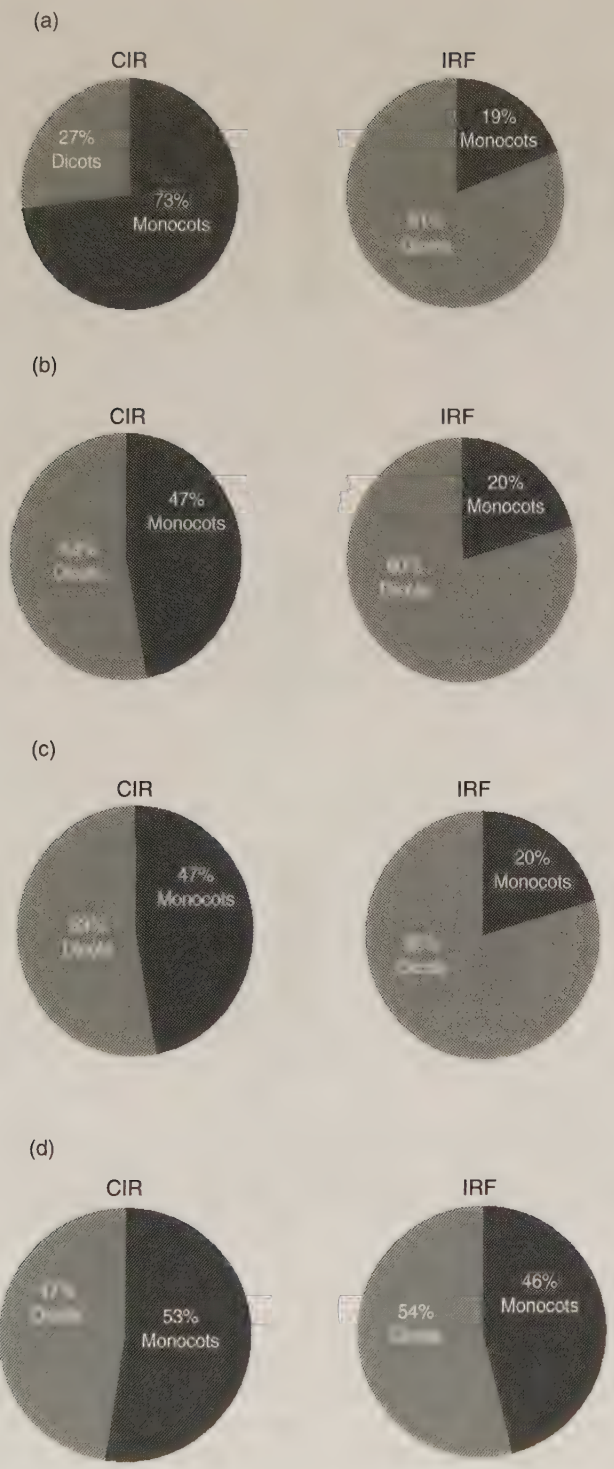

Figure 2. (a–d) Weed growth-form composition in CIR (left) and IRF (right) at 20 and 40 DAT: Abundance and biomass composition.

Simpson (D) diversity indices and Jaccard similarity index[24]. Dendrograms of floristic similarity were constructed with the program FITOPAC[25]. We also report on functional composition [monocotyledons versus dicotyledons and (main) species composition].

Statistics

We tested all data for normality of distribution (Kolmogorov–Smirnov and Lilliefors tests)[26,27]. Weed and rice biomass followed normal distribution, whereas normality for abundance data was achieved with ln-transformation. We compared weed communities between systems (CIR versus IRF) and time of sampling (20 and 40 DAT) and related weeds at 40 DAT with rice aboveground biomass, both with individual *t*-tests and in a bi-factorial scheme. Statistical analyses were conducted with Statistica 7.0[28].

Results

Total weed populations

Total weed density and biomass differed between system at 20 and 40 DAT (Fig. 1a). Between 20 and 40 DAT, weed density declined overall (in both production systems) by 70.3% ($P = 0.06$), whereas weed biomass increased overall by 64.0% ($P = 0.05$), resulting in an average overall individual weed biomass increase of 332%.

Total weed density was lower in IRF than in CIR fields, as indicated by *t*-tests. Differences were significant at 20 and 40 DAT. Weed biomass did not differ between systems at 20 DAT, but at 40 DAT was significantly lower in IRF than in the CIR fields. Bi-factorial ANOVAs indicated significant effects of sampling time and rice production system and a tendency for interactions ($P = 0.10$) between these factors for weed density, but no significant effect of treatments on total weed biomass was observed.

Weed type

Monocot density between systems and across sampling dates closely resembled that of total weed density (Fig. 1b), with significant differences at 20 and 40 DAT. Monocot biomass tended to be lower at 20 DAT in the IRF system, but did not differ at 40 DAT.

Bi-factorial analysis indicated significant effects of treatment and time on dicot density (Fig. 1c), with no interaction between factors, and no significant effect between treatments or sampling time for dicot weed biomass.

Bi-factorial analysis indicated significant effects of the rice production system on the relative growth-form composition of weeds between CIR and IRF at 20 and 40 DAT (Fig. 2a–d).

Weed species composition

Table 1 lists the most important weed species in CIR and in IRF at 20 and 40 DAT. Species ranking differed markedly with time and between the two production systems. *Fimbristylis miliacea* and *Pontenderia cordata* were most important in CIR, and *P. cordata* and *Marsilea quadrifolia* were the most important in IRF fields. Most noteworthy was the complete absence of *F. miliacea* (Cyperaceae) in the IRF system. This species is aggressive, disperses

Table 1. Weed species ranking in CIR and IRF production systems at 20 and 40 DAT.

CIR					IRF				
Species	% abund	% biom	% freq	IV[1]	Species	% abund	% biom	% freq	IV[1]
CIR (at 20 DAT)					IRF (at 20 DAT)				
Fimbristylis miliacea (L.) Vahl, Cyperaceae	70.9	49.9	20.7	47.2	*E. crassipes*, (Mart.) Solms, Pontenderiaceae	33.6	16.9	15.9	22.1
Pontenderia cordata L., Pontenderiaceae	12.3	34.1	17.0	21.1	*P. cordata* L., Pontenderiaceae	23.1	22.6	17.5	21.1
Eichornia crassipes (Mart.) Solms, Pontenderiaceae	5.5	4.4	15.1	8.3	*Oryza sativa*, L., Poaceae[2]	19.9	29.6	12.7	20.7
CIR (at 40 DAT)					IRF (at 40 DAT)				
P. cordata L., Pontenderiaceae	37.1	42.4	22.7	34.1	*Marsilea quadrifolia* L., Marsileaceae	44.7	30.8	20.5	32.0
F. miliacea (L.) Vahl, Cyperaceae	26.4	45.0	22.7	31.4	*P. cordata* L., Pontenderiaceae	27.6	38.9	18.2	28.2
Oryza rufipogon, Griff, Poaceae[2]	0.2	0.5	2.3	1.0	*O. rufipogon*, Griff, Poaceae[2]	1.6	14.4	4.6	6.7

[1] IV, importance values, calculated as averages of abundance shares (% abund), biomass shares (% biom) and frequency shares (% freq).
[2] 'Red rice', a low-productivity 'wild rice' variety that tends to turn dominant in areas with repeated irrigated rice cultivation. Red rice is especially difficult to control with herbicides, due to its taxonomic similarity with cultivated rice.

Table 2. Weed diversity at 20 and 40 DAT in IRF and CIR systems (means ± SE).

	20 DAT	40 DAT
Shannon–Weaver (H′)		
IRF	1.27 (± 0.26)	1.25 (± 0.12)
CIR	0.99 (± 0.25)	1.22 (± 0.15)
Simpson (D′)		
IRF	3.27 (± 0.33)	3.17 (± 0.32)
CIR	2.35 (± 0.68)	2.96 (± 0.66)

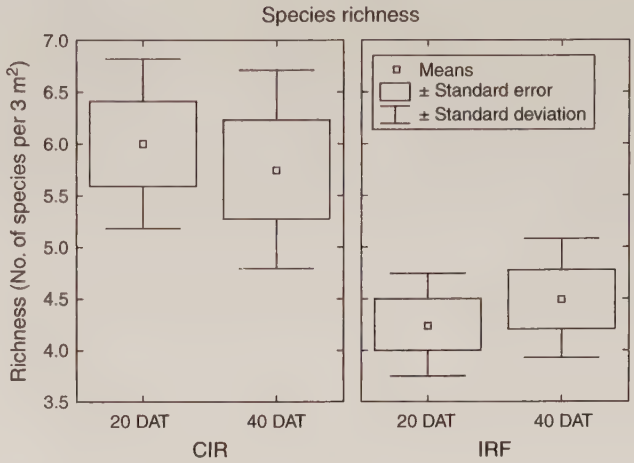

Figure 3. Comparison of CIR and IRF systems on weed species richness at 20 and 40 DAT.

rapidly and causes significant yield reductions in irrigated rice agriculture of the region[29–30].

Weed diversity and similarity

Weed species richness was significantly lower (29%) in IRF compared to CIR at 20 DAT, but not significantly lower (22%) at 40 DAT (Fig. 3).

Weed species richness did not vary significantly over time in each system, and the interaction (time × system) was non-significant. Both Shannon–Weaver (H′) and Simpson (D′) indices did not differ significantly between systems at either sampling date (Table 2). This indicates that, in spite of the substantial reductions in weed biomass and abundance, this weed reduction caused by IRF management did not reduce weed species diversity to the same extent.

Figure 4 compares the floristic similarity (Jaccard index) of weed communities between the CIR and the IRF fields at 20 DAT (top) and 40 DAT (bottom). While floristic similarity was high within the CIR fields and within the IRF fields, the CIR and IRF fields were very dissimilar to one another, thus forming two floristically distinct groups, both at 20 and 40 DAT.

Impact of weeds on rice biomass

Rice aboveground biomass at 40 DAT serves as an indicator of future grain yields[31–34] and was negatively

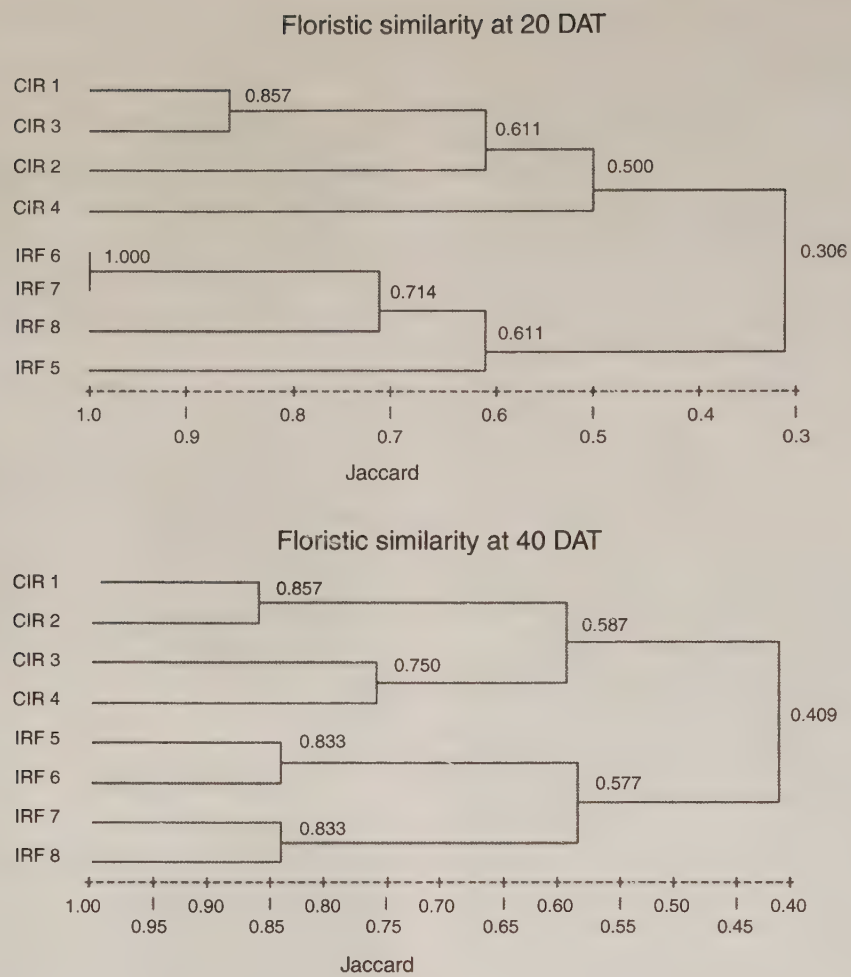

Figure 4. Dendrograms of floristic similarity (Jaccard index) between the eight study fields at 20 DAT (top) and at 40 DAT (bottom). CIR 1–4 are the four CIR fields, whereas IRF 5–8 are the four IRF fields.

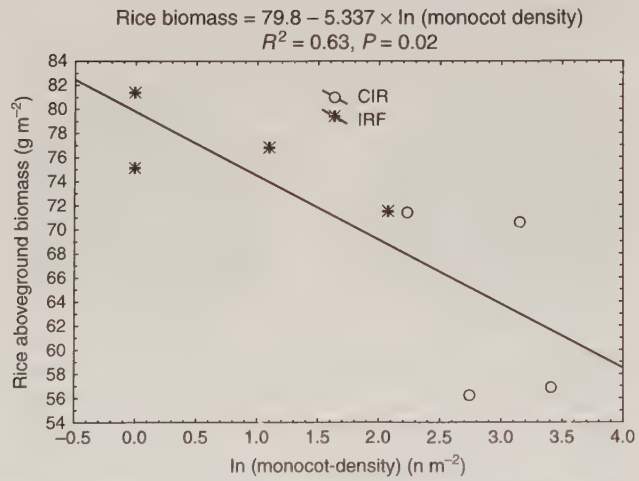

Figure 5. Impact of monocot weed density on rice aboveground biomass at 40 DAT.

affected by total weed density ($R^2 = 0.49$, $P = 0.05$) and by monocot weed density (Fig. 5), but not by weed biomass or dicot weed density.

Discussion

IRF farming is a promising land-use alternative for smallholder riverine farmers of the eastern Amazonian lowlands. With a potential for high productivity in grain and fish yields, this system is capable of generating sufficient income for smallholders. The synergies between the rice and fish components may provide a potential reduction in financial inputs (chemical fertilizers and pesticides) and possibly labor, if manual weeding is reduced. The IRF system may also help eliminate weed seedbanks, as weed control is a key factor in irrigated rice grain productivity and economic returns[35–37].

Due to selectivity problems, chemical weed control is especially difficult for species related to rice cultivars, most notably 'red rice' (*Oryza rufipogon* Griff), a low-productivity 'wild' rice variety that causes serious management problems in the study region[38].

Compared to CIR management, 3 years of integrated rice–fish cultivation drastically reduced weed density. Thus, our study confirms previous findings reviewed by Frei and Becker[39] on weed reductions associated with IRF.

Differences in weed populations and weed reductions associated with IRF were greater in abundance than in biomass, and more apparent at 20 DAT than at 40 DAT. The reasons for this are unknown.

Since IRF effects on weeds are most expressed early (20 DAT) in rice development, this management alternative appears especially effective at the most critical stages of weed control for irrigated rice agriculture.

Weed reduction associated with IRF was also greater for monocotyledons than for dicotyledons. As weed floristic similarity between IRF and CIR fields was low, this may indicate that fish-weeding is species-specific. The underlying reasons for potential species-specificity are unknown. One possible explanation would be that 3 years of continuous IRF management causes a selective depletion of the seed bank of small-sized seeds, which in turn are predominantly monocotyledons. Alternatively, some fish may prefer monocotyledons[40,41], though feeding preference will vary not only with fish species but also with the relative availability of food sources. Since monocotyledonous weeds typically are the more aggressive species and more difficult to control both mechanically and with herbicides[42], IRF appears to provide the best management option for the most important weed families, including Cyperaceae[43,44], in irrigated rice production.

Although the weed density reduction accomplished in a 3-year-old IRF system was significant, this was not accompanied by a reduction in weed species diversity. This may indicate that fish-weeding did not cause a simplification of the weed community.

In the future, we will conduct on-farm investigations of other key aspects of IRF related to the ecological and socioeconomic sustainability and adequacy for smallholder farmers: (i) the substitution of synthetic nitrogen with biological nitrogen fixation via *Azolla*, (ii) the ideal densities, species and management of the critical juvenile stage of fish, (iii) utilization of the field boarders (dikes) for irrigated horticulture, fruit production and for human and fish nutrition and (iv) monitoring of water quality and greenhouse gas emissions (CH_4 and N_2O).

Based on the data presented here, we conclude that IRF cultivation as a land-use system has important positive effects on weed control, apparently without the need for further mechanical or chemical weed control. In this important aspect of irrigated rice management, IRF is thus a land-use system ideally suited for resource-poor smallholder agriculture in environmentally sensitive riverine areas.

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Integrated crops and livestock in central North Dakota, USA: Agroecosystem management to buffer soil change

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Abstract

Integrated crop–livestock systems have been purported to have numerous agronomic and environmental benefits, yet information documenting their long-term impact on the soil resource is lacking. This study sought to quantify the effects of an integrated crop–livestock system on near-surface soil properties in central North Dakota, USA. Soil bulk density, electrical conductivity, soil pH, extractable N and P, potentially mineralizable N, soil organic carbon (SOC) and total nitrogen (TN) were measured 3, 6 and 9 years after treatment establishment to evaluate the effects of residue management (Grazed, Hayed and Control), the frequency of hoof traffic (High traffic, Low traffic and No traffic), season (Fall and Spring) and production system (integrated annual cropping versus perennial grass) on near-surface soil quality. Values for soil properties were incorporated into a soil quality index (SQI) using the Soil Management Assessment Framework to assess overall treatment effects on soil condition. Residue management and frequency of hoof traffic did not affect near-surface soil properties throughout the evaluation period. Aggregated SQI values did not differ between production systems 9 years after treatment establishment (integrated annual cropping = 0.91, perennial grass = 0.93; $P = 0.57$), implying a near-identical capacity of each system to perform critical soil functions. Results from the study suggest that with careful management, agricultural producers can convert perennial grass pastures to winter-grazed annual cropping systems without adversely affecting near-surface soil quality. However, caution should be exercised in applying results to other regions or management systems. The consistent freeze/thaw and wet/dry cycles typical of the northern Great Plains, coupled with the use of no-till management, modest fertilizer application rates and winter grazing likely played an important role in the outcome of the results.

Key words: integrated agricultural systems, soil change, soil quality

Introduction

Integrated crop–livestock systems may improve agricultural productivity, environmental quality, operational efficiency and economic performance relative to specialized, single-enterprise production systems[1,2]. Benefits from crop–livestock integration stem from production synergies brought about by using crops and crop residues for livestock feed while capturing nutrients from livestock wastes for subsequent crop production[3,4]. To date, many positive agronomic and environmental attributes have been associated with integrated crop–livestock systems[5–7]. However, concerns persist regarding the role of livestock in these systems to adversely affect near-surface soil conditions, with potential negative impacts on long-term sustainability[8].

Adding livestock to annual cropping systems can have variable effects on soil condition under different climatic and edaphic environments. In humid and sub-humid regions, soil organic carbon (SOC) and total nitrogen (TN) have been observed to increase with the inclusion of cattle within annually cropped systems or systems with a perennial grass phase[6,9,10]. Increases in SOC and TN in integrated crop–livestock systems have been associated with

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greater aggregate stability and labile organic matter pools in near-surface soil depths[6,7], thereby conferring potential benefits to erosion resistance and nutrient-cycling potential. Evidence of soil compaction from livestock trampling, however, has been observed in regions where soils are often not frozen and moist from precipitation[11]. In these regions, increased penetration resistance caused by cattle traffic during winter grazing has been observed[6,12], with negligible or negative effects on subsequent crop yield[7,13].

Published information addressing soil responses to integrated crop–livestock systems is especially limited in semiarid regions. System effects on soil condition are difficult to document in these regions[14,15], owing primarily to the fact that soil attributes change slowly in response to management due to limited—and often erratic—production of above- and belowground biomass[16]. Accordingly, long-term research is needed to document effects of integrated crop–livestock systems on soil attributes associated with key soil functions.

In 1999, a research team at the USDA-ARS Northern Great Plains Research Laboratory initiated an integrated crop–livestock study designed to evaluate production, nutritional, and environmental aspects of overwintering dry bred cows on swathed annual crops[17,18]. Unlike other integrated crop–livestock studies in the northern US, this project converted perennial grass pastures to annual cropping, thereby placing emphasis on maintaining soil conditions accrued under perennial vegetation. From 2001 through 2008, a suite of soil attributes were measured, with the intention of quantifying treatment effects on near-surface soil quality. Specific objectives associated with the soils component of this study were to evaluate the effects of residue management, frequency of hoof traffic, season and production system (e.g., integrated annual cropping versus perennial grass) on near-surface soil quality. The postulation that conversion of perennial grass pastures to a winter-grazed annual crop management system could be achieved without adversely affecting soil quality was used as a guiding hypothesis for this research effort.

Materials and Methods

Site and treatment description

The experimental site was located at the USDA-ARS Northern Great Plains Research Laboratory's south research station, approximately 5 km south of Mandan, North Dakota, USA (latitude 46°46′35′, longitude 100°54′20′). The site was on gently rolling uplands (0–3% slope) with a silty loess mantle overlying Wisconsin age till. Predominant soils at the study site were Temvik–Wilton silt loams (FAO: Calcic Siltic Chernozems; USDA: Fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls).

In 1999, two 6.0 ha crested wheatgrass [*Agropyron desertorum* (Fisch. ex. Link) Schult.] pastures were sprayed with glyphosate [*N*-(phosphonomethyl) glycine; 0.7 kg a.i. ha^{-1}] twice in mid-May and converted to an annual cropping sequence of oat/pea (*Avena sativa* L./*Pisum sativum* L.), triticale/sweet clover (*Triticum aestivum* × *Secale cereale*/*Melilotus officinalis* L.), and corn (*Zea mays* L.). Beginning in 2007, the crop sequence was changed to oat/alfalfa (*Medicago* spp.)/hairy vetch (*Vicia villosa Roth*)/red clover (*Trifolium pratense* L.), Brown midrib sorghum–sudangrass (*Sorghum bicolor* L. Moench)/sweet clover/red clover and corn, also using no-till planting techniques. Each phase of the 3-year cropping sequence was present in both pastures, which were used as replicates. Oat and triticale/sorghum crop mixtures were seeded in mid-to-late May, while corn was seeded in early June. All crops were seeded using no-till planting techniques with a John Deere 750 no-till drill in 19 cm rows (John Deere, Moline, IL). Fertilizer was applied during seeding every year in all crop phases as urea (70 kg N ha^{-1} for all crops from 1999 to 2006; 35 kg N ha^{-1} for oat and sorghum crop mixtures, and 70 kg N ha^{-1} for corn in 2007 and 2008) and monoammonium phosphate (6 kg N ha^{-1} and 11 kg P ha^{-1} for all crops in all years). Weeds were managed using herbicides following recommended practices by area producers.

The oat and triticale/sorghum crop mixtures were harvested for grain from mid-August to early September with the straw spreader removed from the combine, which created a swath of straw and chaff to facilitate winter grazing. The corn was swathed for forage in mid-to-late September. Each crop strip was split into three residue management treatments that included no residue removal (CONTROL; 0.05 ha), residue removal with a baler (HAYED; 0.05 ha), and residue removal by grazing with livestock (GRAZED; 1.69 ha) (Fig. 1). The CONTROL and HAYED treatments were randomly assigned within each crop strip. For the GRAZED treatment, the swathed crop residues from the cropping sequence represented winter forage for ten 4- to 6-yr-old dry bred Hereford cows, due to calve in late March. Grazing commenced in mid-November and ended in mid-February, with the oat crop mixture grazed first, triticale/sorghum crop mixture second and corn last. Access to crop swaths was controlled using electric fences oriented at right angles to the swaths. Fences were moved daily to provide cows access to fresh forage. A shelter and 'frost-free' fountain were located on the end of each pasture within the GRAZED treatment.

Two 6.0 ha western wheatgrass [*Pascopyrum smithii* (Rydb.) Love] pastures were used as a perennial grass treatment for comparison with the annually cropped treatments. Similar to GRAZED treatments, swathed grass from the pastures was used as winter forage from 1999 through 2002 for the same number of cows managed similarly as outlined above. Within each perennial pasture a non-grazed strip was split into HAYED and CONTROL treatments as outlined above. Due to a lack of adequate forage from drought in 2002 and 2003, the perennial grass treatment was hayed but not grazed in 2003. From 2004 through 2008, the perennial grass treatment was not swathed but lightly grazed with ten Hereford or Angus cows from mid-October to mid-January. Additional details

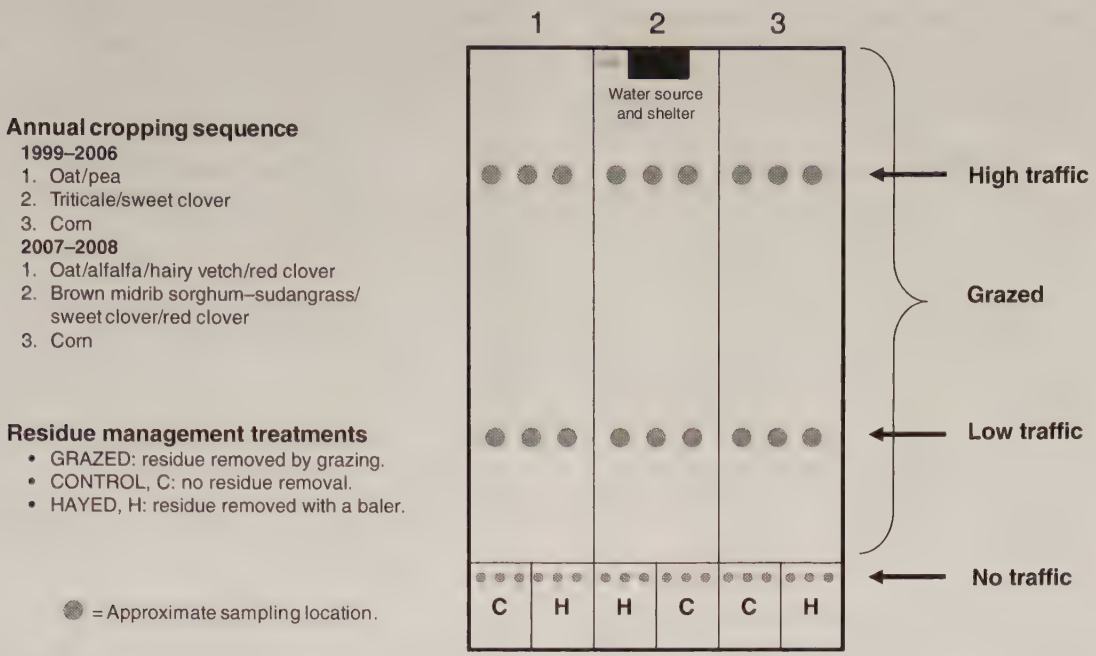

Figure 1. Diagram of residue management and hoof-traffic treatments within an integrated annual cropping pasture near Mandan, ND.

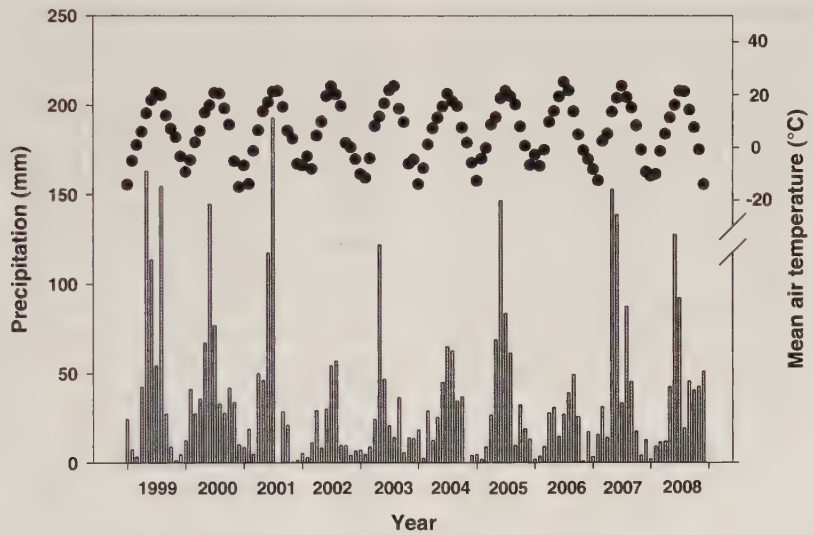

Figure 2. Monthly precipitation and mean monthly air temperature near study site, 1999–2008.

regarding crop and livestock aspects of the experiment are reviewed elsewhere[17,18].

Soil sampling protocol and analysis

Soil samples were collected during the spring (April) and fall (October) of 2001/2002, 2004/2005 and 2007/2008, either after crops had been swathed but not grazed, and after the swathed crops had been grazed but not replanted. Within the annually cropped pastures, samples were collected from nine subplots (three per crop phase) in the CONTROL and HAYED treatments, oriented randomly in each treatment but between crop rows. Samples from the GRAZED treatment were collected from two transects differing in frequency of hoof traffic, also between crop rows. Nine subplots (three per crop phase) were established in each transect perpendicular to crop swaths approximately 100 m (representing high traffic (HT)) and 200 m (representing low traffic (LT)) from the shelter and water source (Fig. 1). Sampling protocol for the western wheatgrass pastures mirrored that in the annually cropped pastures, with the exception of fewer subplots in each treatment (three in the CONTROL, HAYED and GRAZED hoof-traffic transects). Within each subplot, six soil cores were collected from 0 to 7.5 cm depth using a 3.5-cm (i.d.) step-down probe and composited. Each sample was saved in a double-lined plastic bag, placed in cold storage at 5°C, and analyzed within 6 weeks of collection.

Table 1. Effects of grazing and residue management on soil properties at 0–7.5 cm in the spring of 2002, 2005 and 2008 for a winter grazing management system near Mandan, ND.

Year	Grazed	Hayed	Control	*P-value*
	Soil bulk density ($Mg\,m^{-3}$)			
2002	1.08 (0.04)[1]	1.06 (0.03)	1.06 (0.03)	*0.95*
2005	1.03 (0.04)	1.10 (0.03)	1.12 (0.03)	*0.77*
2008	1.20 (0.08)	1.11 (0.04)	1.13 (0.07)	*0.57*
P-value	*<0.01*	*0.13*	*0.11*	
	Electrical conductivity ($dS\,m^{-1}$)			
2002	0.25 (0.04)	0.22 (0.03)	0.25 (0.02)	*0.56*
2005	0.32 (0.04)	0.28 (0.03)	0.28 (0.02)	*0.45*
2008	0.46 (0.03)	0.36 (0.02)	0.45 (0.01)	*0.45*
P-value	*<0.01*	*<0.01*	*<0.01*	
	Soil pH ($-\log[H^+]$)			
2002	5.88 (0.06)	5.89 (0.08)	5.93 (0.13)	*0.97*
2005	5.92 (0.06)	6.06 (0.08)	6.13 (0.13)	*0.73*
2008	5.83 (0.12)	5.99 (0.23)	6.14 (0.27)	*0.74*
P-value	*0.36*	*0.13*	*0.25*	
	Soil nitrate (kg NO_3-N ha^{-1})			
2002	5.4 (2.6)	4.6 (2.1)	6.9 (2.2)	*0.54*
2005	8.0 (2.6)	5.7 (2.1)	6.4 (2.2)	*0.44*
2008	15.2 (1.6)	9.1 (1.8)	11.3 (1.6)	*0.39*
P-value	*<0.01*	*0.12*	*0.08*	
	Soil ammonium (kg NH_4-N ha^{-1})			
2002	2.0 (1.5)	1.2 (0.5)	1.9 (0.1)	*0.52*
2005	2.1 (1.5)	2.2 (0.5)	2.5 (0.2)	*0.48*
2008	6.3 (1.1)	4.9 (0.5)	4.4 (0.3)	*0.75*
P-value	*0.01*	*<0.01*	*0.01*	
	Available P (kg P ha^{-1})			
2002	7.8 (1.2)	6.1 (1.1)	6.1 (2.2)	*0.24*
2005	8.1 (1.2)	5.5 (1.1)	8.8 (2.2)	*0.74*
2008	15.7 (2.3)	11.1 (1.1)	11.6 (1.7)	*0.20*
P-value	*<0.01*	*<0.01*	*0.07*	
	Potentially mineralizable N (kg N ha^{-1})			
2002	63.5 (6.9)	53.7 (6.2)	65.5 (11.6)	*0.40*
2005	65.1 (6.9)	71.8 (6.2)	76.7 (11.6)	*0.62*
2008	75.0 (8.9)	61.1 (4.7)	52.5 (6.7)	*0.27*
P-value	*0.22*	*0.03*	*0.15*	
	SOC (Mg C ha^{-1})			
2002	23.9 (1.5)	23.2 (1.0)	23.3 (1.9)	*0.89*
2005	20.6 (1.5)	21.9 (1.0)	23.1 (1.9)	*0.15*
2008	25.6 (1.0)	23.8 (1.5)	22.2 (1.8)	*0.54*
P-value	*0.01*	*0.21*	*0.83*	
	TN (Mg N ha^{-1})			
2002	2.1 (0.1)	2.1 (0.1)	2.1 (0.2)	*0.76*
2005	1.8 (0.1)	1.9 (0.1)	2.0 (0.2)	*0.23*
2008	2.3 (0.1)	2.2 (0.1)	2.1 (0.1)	*0.60*
P-value	*<0.01*	*0.02*	*0.92*	

[1] Values in parentheses represent mean standard error.

Table 2. Effects of frequency of hoof traffic on soil properties at 0–7.5 cm in the spring of 2002, 2005, and 2008 for an integrated annual cropping system near Mandan, ND.

Year	High traffic	Low traffic	No traffic	*P-value*
	Soil bulk density ($Mg\,m^{-3}$)			
2002	1.08 (0.09)[1]	1.03 (0.08)	1.07 (0.03)	*0.93*
2005	1.01 (0.09)	1.08 (0.08)	1.13 (0.03)	*0.79*
2008	1.19 (0.10)	1.16 (0.09)	1.11 (0.05)	*0.37*
P-value	*0.24*	*0.45*	*0.15*	
	Electrical conductivity ($dS\,m^{-1}$)			
2002	0.25 (0.15)	0.23 (0.04)	0.24 (0.01)	*0.79*
2005	0.29 (0.15)	0.31 (0.04)	0.27 (0.01)	*0.39*
2008	0.52 (0.10)	0.39 (0.03)	0.41 (0.01)	*0.65*
P-value	*0.20*	*0.14*	*<0.01*	
	Soil pH ($-\log[H^+]$)			
2002	5.72 (0.07)	5.69 (0.08)	5.88 (0.11)	*0.99*
2005	5.56 (0.07)	5.80 (0.08)	6.07 (0.11)	*0.60*
2008	5.80 (0.07)	5.78 (0.15)	6.03 (0.21)	*0.68*
P-value	*0.04*	*0.46*	*0.25*	
	Soil nitrate (kg NO_3-N ha^{-1})			
2002	5.3 (6.7)	5.4 (2.0)	5.3 (0.1)	*0.89*
2005	6.0 (6.7)	7.7 (2.0)	5.5 (0.1)	*0.38*
2008	20.2 (4.7)	11.6 (1.4)	9.7 (0.6)	*0.32*
P-value	*0.10*	*0.17*	*<0.01*	
	Soil ammonium (kg NH_4-N ha^{-1})			
2002	2.2 (4.3)	1.4 (1.0)	1.5 (0.2)	*0.70*
2005	2.0 (4.3)	2.3 (1.0)	2.4 (0.2)	*0.35*
2008	9.4 (3.0)	5.4 (0.7)	4.4 (0.2)	*0.48*
P-value	*0.21*	*0.11*	*<0.01*	
	Available P (kg P ha^{-1})			
2002	9.3 (2.8)	6.8 (2.8)	6.5 (1.8)	*0.17*
2005	6.8 (2.8)	8.6 (2.8)	6.9 (1.8)	*0.97*
2008	16.8 (3.9)	15.2 (2.0)	10.8 (1.7)	*0.42*
P-value	*0.02*	*0.17*	*0.07*	
	Potentially mineralizable N (kg N ha^{-1})			
2002	57.2 (11.5)	55.4 (17.7)	59.7 (11.3)	*0.42*
2005	65.9 (11.5)	56.0 (17.7)	70.1 (11.3)	*0.70*
2008	59.4 (8.1)	89.8 (14.0)	56.7 (8.0)	*0.23*
P-value	*0.74*	*0.29*	*0.47*	
	SOC (Mg C ha^{-1})			
2002	23.0 (1.1)	25.0 (5.6)	23.4 (1.9)	*0.59*
2005	19.0 (1.1)	20.3 (5.6)	22.9 (1.9)	*0.14*
2008	25.8 (1.0)	20.8 (3.9)	21.6 (1.7)	*0.43*
P-value	*<0.01*	*0.70*	*0.63*	
	TN (Mg N ha^{-1})			
2002	2.1 (0.1)	2.2 (0.5)	2.1 (0.2)	*0.40*
2005	1.7 (0.1)	1.8 (0.5)	2.0 (0.2)	*0.13*
2008	2.4 (0.1)	1.9 (0.3)	2.0 (0.1)	*0.42*
P-value	*<0.01*	*0.74*	*0.89*	

[1] Values in parentheses represent mean standard error.

Soil samples were dried at 35°C for 3–4 days and then ground by hand to pass a 2.0 mm sieve. Identifiable plant material (>2.0 mm diameter, >10 mm length) was removed during sieving. Electrical conductivity and pH were estimated from a 1:1 soil–water mixture[19,20]. Soil NO_3-N and NH_4-N were determined from 1:10 soil-KCl (2 M) extracts using cadmium reduction followed by a modified Griess–Ilosvay method and indophenol blue reaction[21]. Plant-available soil P was estimated by bicarbonate extraction[22]. Potentially mineralizable N was estimated from the NH_4-N accumulated after a 7-day anaerobic incubation at 40°C[23]. Total soil C and N was determined by dry combustion using a Carlo Erba NA 1500 CN analyzer (Thermo Scientific, Waltham, MA, USA)[24]. Soil pH was <7.2 for the depths sampled, and so total soil C was considered equivalent to SOC. Gravimetric data were converted to a

Table 3. Seasonal effects of winter grazing on soil properties at 0–7.5 cm within an integrated crop–livestock system near Mandan, ND. Sampling times corresponded to the time after crops had been swathed but not grazed (fall) and after the swathed crops had been grazed but not replanted (spring).

Sampling time	Soil bulk density ($Mg\,m^{-3}$)	Electrical conductivity ($dS\,m^{-1}$)	Soil pH ($-\log[H^+]$)	Soil nitrate kg NO_3-N ha^{-1}	Soil ammonium (kg NH_4-N ha^{-1})	Available P (kg P ha^{-1})
Fall, 2001	1.08 (0.02)[1]	0.35 (0.01)	5.91 (0.05)	14.8 (2.6)	0.7 (0.4)	5.6 (0.6)
Spring, 2002	1.08 (0.04)	0.25 (0.02)	5.88 (0.10)	5.4 (1.3)	2.0 (0.4)	7.8 (0.5)
P-value	*0.93*	*< 0.01*	*0.55*	*< 0.01*	*< 0.01*	*< 0.01*
Fall, 2004	1.03 (0.03)	0.28 (0.02)	6.00 (0.06)	5.6 (0.9)	1.4 (0.1)	4.6 (0.8)
Spring, 2005	1.03 (0.07)	0.32 (0.02)	5.91 (0.16)	8.0 (0.9)	2.1 (0.2)	8.1 (1.9)
P-value	*0.98*	*0.27*	*0.14*	*0.21*	*< 0.01*	*< 0.01*
Fall, 2007	1.10 (0.05)	0.33 (0.04)	5.78 (0.07)	6.7 (2.8)	4.8 (1.8)	14.6 (1.5)
Spring, 2008	1.20 (0.06)	0.46 (0.04)	5.83 (0.16)	15.2 (1.7)	6.3 (1.4)	15.7 (1.8)
P-value	*0.04*	*< 0.01*	*0.48*	*0.01*	*0.40*	*0.45*

[1] Values in parentheses represent mean standard error.

volumetric basis for each sampling depth using field measured soil bulk density[25]. All data were expressed on an oven-dry basis prior to statistical analysis.

Data analyses

Analysis of variance was conducted with PROC mixed in SAS using a repeated measures analysis technique for testing effects of residue management, hoof traffic, season, year and production system on soil properties[26,27]. For each analysis, tested effects were considered fixed, while replicates were considered random. Treatment means were calculated across subplots and crop phases. A significance criterion of $P \leqslant 0.05$ was used to document differences between means.

Only data from the spring samplings were used for the residue management, hoof traffic and production system comparisons. Additionally, for frequency of hoof traffic, data from the CONTROL and HAYED treatments were combined to represent a no-traffic treatment (NT). Similarly, only data from the GRAZED treatment were used to compare seasonal effects on soil properties.

To assess production system effects on an integrative measure of soil quality, values for select soil properties were included in a soil quality index (SQI) using the Soil Management Assessment Framework (SMAF)[28]. The SMAF follows a three-step framework including (1) indicator selection, (2) indicator interpretation, and (3) integration into an SQI score. Briefly, data from six soil properties were used for step one: soil bulk density, electrical conductivity, soil pH, extractable P, potentially mineralizable N and total C. Non-linear scoring algorithms were used for step two to assign a score for each property (ranging from 0 to 1, with 1 representing highest potential soil function). To ensure that algorithms were appropriate for the edaphic, climatic and management attributes associated with the study site, appropriate factor class assignments were selected based on categories in the SMAF[28]. Individual property scores were summed and a mean value was calculated for step three to arrive at an aggregated SQI score. Individual property and SQI scores were subject to statistical analyses for production system comparisons as outlined above.

Results

From 1999 through 2008, weather patterns in most years followed trends typical of a semiarid continental climate, with cold and dry winters and warm to hot summers with erratic precipitation (Fig. 2). Mean annual precipitation over the 10-year period was 430 mm, slightly above the long-term (94-years) mean of 413 mm. Four years were marked by drought (2002–2004, 2006), where a lack of precipitation during the spring and summer months resulted in mean annual precipitation ranging from 228 to 335 mm. Mean monthly air temperatures followed expected seasonal patterns and rarely deviated by more than ±3°C from long-term means (Fig. 2)[29].

Residue management

Residue management did not affect near-surface soil properties in any year (Table 1). Across years, soil bulk density increased within the GRAZED treatment between 2005 and 2008, although increases were not sufficient to limit root growth[30]. Significant increases in electrical conductivity between 2005 and 2008 in all residue management treatments were driven by greater extractable N and P in 2008, the result of residual plant nutrients left in soil following the 2006 and 2007 growing seasons, early spring mineralization (N only, as discussed below) and/or manure accumulation (GRAZED only). Soil pH ranged from moderately to slightly acid and did not differ between years in any residue management treatment. Potentially mineralizable N increased significantly between 2002 and 2005 in the HAYED treatment ($\triangle = 18.1$ kg N ha^{-1}), the cause of which is unclear. Soil organic C (SOC) and TN increased between 2005 and 2008 in the GRAZED treatment

($\triangle = 5.0$ Mg C ha^{-1} and 0.5 Mg N ha^{-1}, respectively). The increase in SOC and TN may have been driven by manure accumulation in the GRAZED treatment; although it is important to acknowledge the elevated soil bulk density in 2008, which would act to contribute to greater SOC when expressed volumetrically. Conversely, increased soil bulk density could not account for elevated TN in the HAYED treatment in 2008 as compared to 2005.

Frequency of hoof traffic; season

Frequency of hoof traffic within the integrated annual cropping system did not affect near-surface soil properties in any year (Table 2). Available P, SOC, and TN increased between 2005 and 2008 in the high-traffic zone (HT), possibly the result of greater manure accumulation from cattle due to the relatively close proximity of the zone to the winter shelter and water source (approximately 100 m). Similar to the residue management treatments, increased extractable N and P in 2008 within the no-traffic zone (NT) was likely the result of residual plant nutrients in soil following the previous growing season, early spring mineralization and/or manure accumulation.

Winter grazing of annual crops had minor effects on near-surface soil properties (Table 3). Of the three contrasted sampling times (i.e., 2001/2002, 2004/2005 and 2007/2008), changes in soil properties between fall and spring were most prevalent in 2001/2002 and least prevalent in 2004/2005. Soil bulk density increased following winter grazing between fall 2007 and spring 2008 by 0.1 Mg m^{-3}, possibly the result of hoof-induced compaction in December 2007. Trends in electrical conductivity and soil NO_3-N were similar between spring and fall in 2001/2002 and 2007/2008, with both parameters decreasing (2001/2002) or increasing (2007/2008) following grazing. The inconsistent trend between years was likely due to either NO_3-N loss following spring snowmelt (e.g., leaching, nitrification/denitrification) or NO_3-N release from mineralized organic material. Both soil NH_4-N and available P increased between spring and fall in 2001/2002 and 2004/2005; although increases were numerically small ($\triangle = 0.7$–1.3 kg NH_4-N ha^{-1}; 2.2–3.5 kg P ha^{-1}).

Production system

Comparisons between integrated annual cropping and perennial grass treatments exhibited few differences in near-surface soil properties in 2002, 2005 and 2008 (Table 4). The application of N and P fertilizers contributed to greater soil NO_3-N (2005, 2008) and available P (2008) under integrated annual cropping compared to perennial grass. Conversely, potentially mineralizable N was greater under perennial grass than integrated annual cropping, a finding that confirms previous comparisons of annual and perennial agroecosystems in temperate regions[31,32].

Changes in near-surface soil properties between sampling times were common for both production systems (Table 4). Notable changes included significant increases in extractable N, available P and electrical conductivity in the integrated annual cropping system between 2005 and 2008; increases likely caused by residual plant nutrients from fertilizer not utilized by crops (in the case of P), early spring N mineralization, and/or manure accumulation. A similar trend was observed under perennial grass, but

Table 4. Soil properties at 0–7.5 cm in the spring of 2002, 2005 and 2008 for integrated annual cropping and perennial grass near Mandan, ND.

Year	Integrated annual cropping	Perennial grass	*P-value*
	Soil bulk density (Mg m^{-3})		
2002	1.07 (0.02)[1]	1.02 (0.02)	*0.49*
2005	1.07 (0.02)	1.11 (0.02)	*0.73*
2008	1.16 (0.07)	1.07 (0.02)	*0.29*
P-value	*< 0.01*	*< 0.01*	
	Electrical conductivity (dS m^{-1})		
2002	0.24 (0.02)	0.25 (0.02)	*0.70*
2005	0.30 (0.02)	0.29 (0.02)	*0.56*
2008	0.43 (0.01)	0.37 (0.02)	*0.25*
P-value	*< 0.01*	*< 0.01*	
	Soil pH ($-\log[H^+]$)		
2002	5.89 (0.06)	6.46 (0.10)	*0.08*
2005	6.00 (0.06)	6.58 (0.10)	*0.09*
2008	5.94 (0.18)	6.88 (0.08)	*0.06*
P-value	*0.18*	*< 0.01*	
	SN (kg NO_3-N ha^{-1})		
2002	5.6 (1.5)	0.7 (0.2)	*0.06*
2005	7.0 (1.5)	1.3 (0.2)	*0.02*
2008	12.7 (1.0)	0.9 (0.3)	*0.03*
P-value	*< 0.01*	*0.02*	
	Soil ammonium (kg NH_4-N ha^{-1})		
2002	1.8 (0.3)	1.9 (0.2)	*0.77*
2005	2.2 (0.1)	2.6 (0.2)	*0.13*
2008	5.5 (0.7)	4.0 (0.2)	*0.32*
P-value	*0.03*	*< 0.01*	
	Available P (kg P ha^{-1})		
2002	8.9 (1.0)	6.9 (1.0)	*0.18*
2005	7.6 (1.0)	2.2 (1.0)	*0.24*
2008	13.5 (1.6)	5.2 (0.7)	*0.02*
P-value	*< 0.01*	*< 0.01*	
	Potentially mineralizable N (kg N ha^{-1})		
2002	61.6 (5.1)	91.6 (6.4)	*0.03*
2005	69.7 (5.1)	109.3 (6.4)	*0.04*
2008	65.9 (5.4)	117.2 (4.6)	*0.02*
P-value	*0.28*	*< 0.01*	
	Soil organic C (Mg C ha^{-1})		
2002	23.6 (0.9)	23.8 (1.2)	*0.87*
2005	21.6 (0.9)	21.6 (1.2)	*0.99*
2008	24.3 (0.9)	25.6 (0.7)	*0.44*
P-value	*0.01*	*0.01*	
	TN (Mg N ha^{-1})		
2002	2.1 (0.1)	2.1 (0.1)	*0.72*
2005	1.9 (0.1)	1.8 (0.1)	*0.38*
2008	2.2 (0.1)	2.3 (0.1)	*0.81*
P-value	*< 0.01*	*0.04*	

[1] Values in parentheses represent mean standard error.

Table 5. SMAF index scores in the spring of 2002, 2005 and 2008 for integrated annual cropping and perennial grass near Mandan, ND. Values reflect scores for six soil properties included in SMAF, as well as an aggregated score (SQI) for each year.

Variable[1]	Integrated annual cropping	Perennial grass	*P-value*[2]	Integrated annual cropping	Perennial grass	*P-value*	Integrated annual cropping	Perennial grass	*P-value*
	2002			2005			2008		
SBD	0.99	0.99	*0.47*	0.99	0.99	*0.53*	0.95	0.99	*0.45*
EC	1.00	1.00	*1.00*	1.00	1.00	*1.00*	0.99	1.00	*0.50*
PH	0.98	0.98	*0.67*	0.98	0.98	*0.98*	0.97	0.95	*0.43*
P	0.97	0.91	*0.03*	0.95	0.34	*0.10*	0.99	0.92	*0.07*
PMN	1.00	1.00	*1.00*	1.00	1.00	*1.00*	0.99	1.00	*0.50*
SOC	0.64	0.68	*0.73*	0.56	0.52	*0.75*	0.59	0.71	*0.25*
SQI	0.93	0.93	*0.91*	0.91	0.80	*0.10*	0.91	0.93	*0.57*

[1] SBD, soil bulk density index score; EC, electrical conductivity index score; PH, soil pH index score; P, available phosphorus index score; PMN, potentially mineralizable N index score; SOC, soil organic C index score; SQI, aggregated soil quality index score.
[2] *P*-values reflect comparison between scores within year.

without the increase in soil NO_3-N. Small, but significant increases in soil bulk density were observed in each production system, with soil bulk density greater in 2008 than 2005 for integrated annual cropping and greater in 2005 than 2002 for perennial grass (both increasing by $0.09\,Mg\,m^{-3}$). Large numerical increases in SOC and TN in 2008 contributed to significantly greater values in both production systems when compared with 2005 ($\triangle$ = 2.7–4.0 Mg C ha^{-1}; 0.3–0.5 Mg N ha^{-1}). However, SOC and TN were not different between 2002 and 2008 for either production system.

Among individual soil properties, SMAF index scores differed between production systems only for available P in 2002, being greater under integrated annual cropping than perennial grass (0.97 versus 0.91, respectively; $P = 0.03$) (Table 5). Although not statistically different in 2005, a numerical difference in the available P score between integrated annual cropping and perennial grass ($\triangle = 0.61$) contributed to the largest difference in the aggregated SMAF scores (SQI) between production systems in any year. This difference notwithstanding, SQI scores did not differ between production systems at $P \leqslant 0.05$, implying a similar capacity of each system to perform critical soil functions.

Discussion

Soil resistance has been defined as the capacity of a soil to continue to function without change throughout a disturbance[33,34]. Small changes in soil function resulting from disturbance imply high resistance, whereas large changes in soil function suggest low resistance. The capacity of soil to maintain functional integrity under disturbance reflects a key component of agroecosystem stability[35]. Such an attribute is increasingly important given the context of 21st century agriculture, where concurrent trends of increased demand for agricultural products, increasingly scarce non-renewable resources and accelerating climate change will favor agroecosystems that are resistant to change yet highly productive[36].

We sought to quantify the effects of disturbance (residue management, frequency of hoof traffic, season and production system) on near-surface soil quality for an integrated crop–livestock system in central North Dakota. Overall, results from the study suggest disturbances had minimal effects on soil properties during the timeframe of measurement, with no differences in soil function between integrated annual cropping and perennial grass at 3, 6 and 9 years after study establishment. While the lack of significant treatment effects may be disconcerting to some readers, our data demonstrate that sustainable agroecosystem management mitigates significant alterations to the soil environment. While management-related factors certainly contributed in conferring resistance to soil disturbance over time, inherent features related to weather and soil may also have played a role.

Inherent weather- and soil-related features may have contributed to soil resistance through annual freeze–thaw and wet–dry cycles characteristic of soils in the northern Great Plains. Such cycles would act to expand/contract soil minerals and water in soil pores, thereby ameliorating compaction caused by cattle and/or vehicular traffic by fracturing compacted soil zones[37,38]. Accordingly, these cycles would act to mitigate changes in near-surface soil bulk density over time.

In addition to weather-related features, the inherent fertility of the soils evaluated in the study may have made the soil more resistant to disturbance. As Pachic and Typic Haplustolls, the soils possessed high inherent fertility (82 Mg SOC ha^{-1}), large buffering capacity (18 cmol kg^{-1} cation exchange capacity), and a favorable particle-size distribution (280 g kg^{-1} sand, 190 g kg^{-1} clay) for supporting critical soil functions (data pertains to 0–30 cm)[39]. Accordingly, deterioration or improvement of this soil under different management would be expected to occur slowly, and most likely on a decadal timescale[16].

Management-related factors governing soil resistance in the integrated annual cropping system may have been associated with the use of no-till seeding operations, as well as the fertility and grazing regimes employed throughout the study. No-till conversion of the crested wheatgrass pastures to annual cropping in 1999 likely conferred an inherent resistance against changes in near-surface soil properties caused by subsequent disturbances from cropping and grazing. A lack of tillage during conversion to annual cropping allowed for the maintenance of soil structure (e.g., pore continuity and pore-size distribution) developed under perennial grass[40]. Maintenance of a favorable soil structure during the transition to annual cropping may have been critical in buffering potential changes in soil condition caused by differences in plant type (annual crops versus perennial grass) and the implementation of field activities (e.g., spraying, planting and swathing). Moreover, the use of no-till operations negated tillage-induced 'flushes' of mineralized nutrients typically observed in tilled agroecosystems[41,42]. Tillage is well documented to contribute to seasonal fluctuations in available nutrients and decreased SOC in temperate agroecosystems[16,43].

Modest application rates of N and P fertilizer, coupled with relatively high production of aboveground biomass, likely contributed to low levels of residual nutrients in soil throughout the study. The application of N to soil was lower than recommended for traditional no-till cropping systems in North Dakota[44], but was deemed adequate in order to take advantage of N-fixing legumes in the crop sequence. Production of total aboveground biomass in the integrated annual cropping system was impressive early in the study, ranging from 1.7 to 9.2 Mg ha^{-1} for oat/pea, from 3.2 to 13.8 Mg ha^{-1} for triticale/sweet clover and from 12.8 to 26.9 Mg ha^{-1} for corn from 1999 to 2002[18]. Biomass production at these levels would act to draw down residual nutrient levels, leaving limited soil N and P for subsequent crop production.

Because near-surface soil depths were typically frozen from November through March, soil in the GRAZED treatment was less susceptible to compaction by hoof traffic than if grazing had occurred in the fall or spring, when excessive soil moisture can increase the potential for hoof-induced compaction[45]. Mid-winter warming periods during the grazing time would act to thaw near-surface soil, thereby increasing the likelihood of surface compaction. Relatively warm air temperatures at the study site in December 2007 (8 days >0°C from December 1 to December 31)[46] created the potential for this to occur, which may explain the significant increase in soil bulk density between fall 2007 and spring 2008 in the GRAZED treatment.

Conclusions

Results from this study suggest that winter grazing by cattle in an integrated annual cropping system will not adversely affect near-surface soil properties associated with key soil functions. These results underscore the value of designing and implementing management systems that minimize significant changes to the soil environment. However, caution should be exercised in applying these results outside of the northern Great Plains or to other management systems. The consistent freeze/thaw and wet/dry cycles characteristic of the region, coupled with the use of no-till management, modest fertilizer application rates and winter grazing likely played an important role in the outcome of the results.

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Mapping potential foodsheds in New York State by food group: An approach for prioritizing which foods to grow locally

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Abstract

Public interest in local food continues to grow, but few analyses have examined the capacity for the US population to be supplied through local and regional food systems. This paper extends earlier work that demonstrated a method for mapping potential foodsheds and estimating the potential for New York to meet the food needs of the state's population centers. It provides a methodology for addressing the question, 'If land is limited, which foods should be grown locally?' A spatial model was developed to allocate the available agricultural land of New York State (NYS) to meet in-state food needs for six distinct food groups (grains, vegetables, fruits, dairy, meat and eggs) across the eight largest population centers. An optimization routine was used to allocate land to maximize economic land use value (LUV). Eleven scenarios were examined, ranging from a baseline level of consumption of New York produced foods to a 100% local diet. Across the 11 scenarios, the amount of food supplied, the LUV attained, and the area of land allocated increased as the 'willingness' to consume local products increased. This approach dictated that land was preferentially devoted to higher-value food groups relative to lower-value groups, and no scenario used all available land. Under the 100% local scenario, 69% of total food needs (on a fresh weight basis) were supplied in-state with an average food distance of 238 km. This scenario provided food from only four of the six groups, namely, dairy, eggs, fruit and vegetables. These results suggest that a much larger proportion of total food needs (on a weight basis) might be provided from in-state production than was found in previous work. LUV serves as a compelling optimization function, and future work should investigate the degree to which maximizing returns to land complements or conflicts with social and environmental goals of local and regional food systems.

Key words: geographic information systems (GIS), land use value, local diets, local food systems, optimization, modeling, production capacity, regional food systems

Introduction

A conversation has been evolving in North America and Europe about the role local and regional food systems can and should play in creating more sustainable societies. This discussion has ebbed and flowed for many years, and the origins of this debate within the US have been traced to a literature that was developed in the 1970s[1]. While, these earlier writings tended to postulate why modern society should obtain more of its food from sources closer to the point of consumption, current debate focuses on two key questions. First, do 'local foods' offer real ecological, economic and social benefits? Second, can 'local food' move beyond niche markets and supply a significant share of total food demand? No consensus has been reached on either question, but the existing literature provides insight on where further work is needed.

Several appeals have been made to avoid characterizing locally produced food as inherently more sustainable than food distributed through national and international channels[2–4]. These warnings are warranted. Martinez et al.[5] reviewed the literature and found few studies that evaluated

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the economic, health and environmental benefits of local food systems. They concluded that the issue constitutes an important data gap. Similarly, Edwards-Jones et al.[6] evaluated the evidence regarding the energy use and greenhouse gas emissions benefits of local food and found existing information to be insufficient to evaluate these impacts for any food system. Even if sufficient data were available, adequate comparisons of local and conventional food supply chains may be misleading because, as Schönhart et al.[4] point out, existing local food systems may have significant potential for improved efficiencies.

In spite of these data limitations, public interest in and consumption of local foods fuels discussion about the potential for local food to supply a greater share of food needs. Two articles in a recent issue of *Choices* magazine, a publication of the American Agricultural Economics Association, address this issue. King et al.[7] outline the challenges of 're-localizing' foods in mainstream supermarkets. While significant hurdles exist, the authors see growth potential for the local food sector, similar to that already seen in the organic sector. Clancy and Ruhf[8] argue that local food systems will not be sufficient to provide food in large volumes and at reasonable cost to large populations. Rather, they claim that development of regional food systems will be better able to deliver the economic, environmental and social benefits often attributed to local food systems. The extent to which local and regional food systems can expand remains to be seen.

Attempts to measure the capacity for foods to be supplied from 'local' sources have been made periodically since the early 1980s for a variety of locations[9–16]. These studies vary in methodology, so it is difficult to reach general conclusions about local food in the US. However, multiple studies[9,13,15,16] have estimated New York State's (NYS's) capacity to supply local food, and all have found that capacity is just a fraction of total food needs (from 22 to 34%). Given its high population density and relatively modest endowment of agricultural land, New York can be seen as a microcosm of the Northeast US. In this part of the country, and perhaps in other heavily urbanized areas, food will continue to be sourced from regions that have lower population densities. This raises the question, 'If all food cannot or will not be produced locally or regionally, which food should be?'

The answer to this normative question depends on which societal goals local and regional food systems are supposed to serve. This paper will examine the question based on an economic goal, namely, maximizing the value of the land based on its agricultural returns. While economic rents may not be the most important reason to promote local and regional food systems, all agree that the empirical evidence shows that economic returns influence land use decisions. According to the theory of highest and best use, land tends to be used for the purpose that generates the greatest return, given the available market[17]. A classic example of this principle is the conversion of farmland to residential or other urban uses. Similarly, patterns of agricultural land utilization in metropolitan areas demonstrate how the principal of highest and best use influences decisions on production of farm commodities. For example, vegetable production, which has a high-use value per acre relative to other agricultural enterprises, often persists in metropolitan areas after lower-value enterprises have been supplanted by development[18].

The principle of highest and best use is also embedded in federal and state land use policies. At the federal level, land retirement programs such as the Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) and farmland protection programs compensate land owners not to convert land to certain uses, such as cropping in the case of CRP or WRP. In these programs, rental payments (or easement prices) are intended to cover the opportunity cost of giving up the right to use land for agricultural purposes (i.e., cropping or grazing)[19]. These payments appear to be effective. Lubowski et al.[20] attribute the reduction in the area of active cropland that occurred between 1982 and 1997 largely to the institution of CRP[20]. As a result, the United States Department of Agriculture (USDA) employs models based on expected returns to land to estimate the land use changes that would result from elimination of payments through CRP[21] and WRP[22]. Thus, the value of land can be a compelling lens through which to explore the question of which foods should be grown locally.

The primary goal of this paper is to evaluate the capacity for NYS to meet its food needs while prioritizing which foods should be produced locally and regionally. This issue is explored using a 'foodshed analysis'[23] framework. Throughout the paper, the term 'foodshed' refers to a geographic area that could potentially supply a population center with food. The approach builds on earlier analysis of potential, local foodsheds in NYS[16], and adds to a small but growing body of research using spatial analysis techniques to measure the potential for supplying food needs locally. While our previous work attempted to map theoretical foodsheds by minimizing food miles, this study mapped potential local foodsheds that maximize returns to land.

Methods

A hybrid spatial-analysis-optimization modeling approach was used to evaluate the capacity for NYS population centers to meet food needs within the state's boundaries and thereby map *potential local* foodsheds. The model characterizes the food production potential of the state's cropland and pasture and the food needs of its population centers within a geographic information system (GIS). The GIS provided input for an optimization model that allocated NYS food production capacity to meet the food needs of NYS population centers while maximizing economic returns to land. The details of each step are outlined in the subsequent sections.

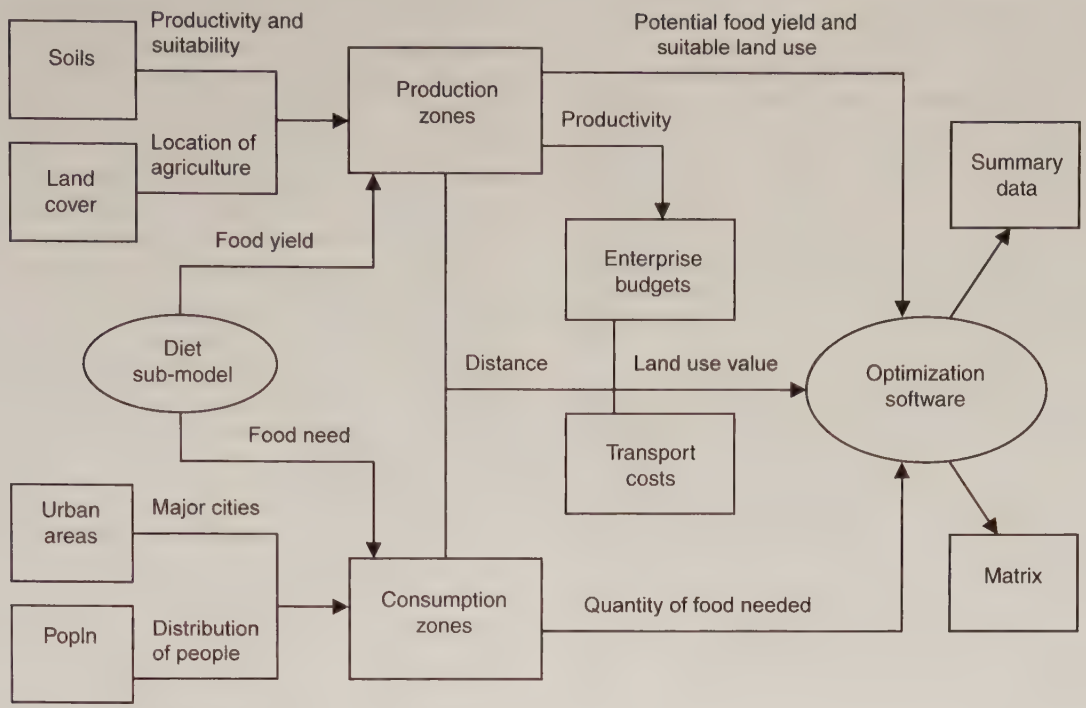

Figure 1. Generalized spatial flow diagram for the foodsheds model.

Outline of model design

A broad range of data were processed to provide the input data for the foodshed optimization model (Fig. 1). Spatial data on land cover and soils provided estimates of the location of agricultural land and the relative productivity of the underlying soils for growing key indicator crops. Urban area delineations and spatially referenced population data were used to define the location of population centers and to estimate the number of people that reside in or near them. Data from prior research on the land requirements of the human diet[13] were used to derive estimates of per capita food need and average NYS food yields.

The GIS provided the platform needed to integrate these data and produce input for the optimization model. Estimates of food production potential were calculated for each food producing unit (production zone) using the information on agricultural land cover, soil productivity and average food yields. Estimates of food needs were calculated for the population living in or around major urban centers (consumption zones). Distances between all production zones and population centers were calculated within the GIS. Data on the potential productivity of the agricultural soils found within production zones were integrated with additional data on transport costs and economic returns to land. These expected returns, when capitalized, were used to estimate land use values (LUVs) for various agricultural enterprises. All data matrices were incorporated into an optimization model that allocated available production to meet the needs of population centers such that the aggregate agricultural LUV of all production zones was maximized. Output from the model was used to map and characterize potential foodsheds. All mapping and geospatial operations were performed using ArcGIS 9.1 and Manifold® System 6.5.

Diet and land requirements

Data from previous research were used to calculate the agricultural land area required to meet the annual food needs of the average person in NYS[13]. Of the 42 diets examined in the earlier study, one diet was selected to represent food need in the foodshed model. The diet provides 2300 kcal per day per person, meets the USDA Food Guide Pyramid (FGP)[24] recommendations for all food groups and relies on meat and eggs as the primary protein sources. Diets were based on representative food commodities from each food group, but, with the exception of sugar crops, only included commodities that are produced in NYS. Per capita intake of each food commodity was estimated based collectively on the quantities of meat and fat included in each diet, the food group recommendations of the FGP, the USDA established serving size for the commodity and the relative preferences for that commodity indicated by national food consumption survey data. Total edible food need was estimated and converted into quantities of agricultural commodities (crops and livestock) by using conversion factors to account for the removal of inedible portions and transformations that occur in food processing. The amount of feed crops necessary to supply the food coming from livestock and poultry products was combined with the food crop estimates and crop yield data to determine the average land requirements of the diet. These estimates assume that cattle, swine and poultry are raised under conventional management.

Agricultural classes and LUV

In the model, farm commodities are divided into six classes: grains, vegetables, fruits, dairy, eggs and meat. These classes group individual crop and animal enterprises based on expected gross returns per acre and some general agronomic similarities. The 'grains' class includes all field crops used for direct human consumption while the livestock classes include the feed crops required to support the animals. Eggs and meat were placed in separate agricultural classes because egg production generates very different returns to land than do meat production enterprises.

Partial enterprise budgets, showing expected costs and returns for these commodities, were assembled and adjusted to reflect agricultural practices on New York's farms (see Appendix 6 of Peters[25]). The budgets represent conventional crop and livestock production practices. Annual net returns were calculated and averaged for the 8-year period, 1997–2004. Because of some data gaps, certain fruit, grain and vegetable crops included in the calculation of dietary land requirements were omitted from the analysis of LUV, but each agricultural class was represented by least three component enterprises.

The calculation of LUV used an approach similar to the method used by the NYS Office of Real Property Services (ORPS) to administer an agricultural tax assessment program[26]. New York law mandates that the agricultural value of farmland be determined using 8-year average net returns to land from crops grown on New York farms[27].

This method was adapted to estimate LUV for each agricultural class (Eqn 1).

$$\mathrm{LUV}_i = \sum w_{ij}((I_{ij} + L_{ij} - M_{ij})/C))/\sum w_{ij} \qquad (1)$$

The LUV of an agricultural class (i) is equal to the weighted average use value of all representative enterprises in an agricultural class. For each enterprise (j), LUV is equal to the net returns to land (average net income (I) plus the average land charge (L) minus a management charge (M)) divided by the capitalization rate (C). Each enterprise is then weighted (w) based on its relative prevalence in New York agriculture. Crop classes are weighted based on the area of land they occupied during the 8-year period. Livestock classes are weighted based on the number of animals in the state's livestock inventory.

Estimating potential food production

As in earlier work[16], the productive potential of NYS soils was determined using two sources of soils data. Spatial data on the distribution of soils were obtained from the State Soil Geographic (STATSGO) database[28]. Information on expected yields and recommended crop rotations for individual soils were obtained from the Master Soils List (MSL), a resource maintained by the Department of Crop and Soil Sciences at Cornell University and published annually by the NYS Department of Agriculture and Markets[29]. Data from STATSGO represent soils in a generalized manner appropriate for statewide and regional analyses[30]. Each STATSGO map unit contains multiple soil types each of which corresponds to a soil-mapping unit from the county-level Soil Survey Geographic (SSURGO) database[30]. The MSL database provides information for all NYS soils, including all the mapping units in the SSURGO database. Thus, the data were integrated by matching each soil component in STATSGO to its corresponding soil in the MSL. The two databases were joined together and expected yields and recommended rotations for good conservation management were calculated for each STATSGO map unit (see Peters[25] for more details). Together, these data provided estimates of the spatial variability in expected yield of two indicator crops, corn (*Zea mays*) silage and hay (multiple species). These forage crops are widely grown throughout NYS to support livestock and milk production. The MSL also provides a corn–hay rotation prescribed for good conservation management. Together, the corn silage yields, hay yields and recommended rotations are used to calculate an index of soil productivity based on the total digestible nutrients (TDN) produced per acre per year in a corn silage and hay rotation.

The location of agricultural land in NYS was determined using the most recent land cover data available at the time the study was conducted, the 1992 National Land Cover Dataset (NLCD)[31]. The 1992 NLCD data were processed to reduce inherent error as recommended by the US Geological Survey[32]. This involved using the data at the most general level of land-cover classification (agriculture, barren, forest, urban, water and wetland) and performing some spatial aggregation (see Appendix 3 of Peters[25] for details).

The combined spatial layers of soil and land cover data displayed potential productivity at a very fine resolution; each pixel represented a 30 m by 30 m land area. In order to avoid the computational issues at this level of resolution, a set of data was created that represented the land area of NYS in 2 km by 2 km grid cells called production zones. Each of these zones was treated as a potential food producing unit. The relative productive potential and land management limitations of each zone were estimated based on a spatial overlay of the production zone boundaries with the layers of combined soils and land cover data. Data from this overlay were used to derive estimates of the area suitable for annual and perennial crops (Eqn 2) and the expected food yields of each agricultural class (Eqn 3).

$$P_{ij} = (A_j \times R_{ij}) \qquad (2)$$

The potential areas (P) suitable for annual and perennial crops are equal to the area of agricultural land (A) in the production zone (j) times the recommended rotation factor (R) for the type of crop (i). For annual crops, R is equal to the number of years corn can be grown in a 10-year rotation divided by 10. For perennial crops, R is equal to the number of years that hay crops should be grown divided by 10. An average R value was calculated for each production zone.

$$Y_{ij} = (\mathrm{TDN}_{ij} \times Y_i)/\overline{\mathrm{TDN}_i} \qquad (3)$$

Figure 2. Map of consumption zones for foodshed analysis. Dots show the geographic center of each major city. Lines demarcate the boundaries of the consumption zones based on the constituent Census Block Groups.

The expected food yield (Y) of a given agricultural class (i) within each production zone (j) was the product of the TDN index for the production zone and the average yield (Y) of food for the agricultural class in NYS divided by the land area weighted average TDN index ($\overline{\text{TDN}}$) of the indicator crop across NYS. The TDN values were calculated from the spatial data layers. Term Y was derived from the earlier study of the land requirements of diet[13] and is expressed in Mg ha^{-1}.

Potential fruit production was handled in a different manner. Winter low temperatures and spring frosts pose threats to perennial fruit crops in temperate climates like New York. To account for the fact that the best locations for fruit production are clustered in certain areas of NYS, spatial data on the location of tax parcels coded as fruit farms were used to approximate suitable locations for fruit production. Spatial tax parcel data were obtained from the NYS ORPS (statewide data for 2004 obtained from L. Morin, personal communication, 2006).

Estimating food needs of population centers

The US Census Bureau's Urbanized Areas and Urban Clusters (UAUC) data[33] were used to identify the locations of population centers. These data delineate clusters of contiguous, highly developed land throughout the US, and thus represent population centers as discrete geographic entities. One hundred and thirty-two of these entities exist in NYS. To constrain the size of the problem while maintaining the resolution of the production zones, we reduced the number of population centers contained in the model by dividing the state's population into eight zones covering the largest urban areas in the state: Albany, Binghamton, Buffalo, New York City, Poughkeepsie-Newburgh, Rochester, Syracuse and Utica (Fig. 2). These zones were created by assigning all census block groups[34] to the nearest major city. The populations contained within each urbanized area and within each consumption zone are shown in Table 1[35].

Adjusting LUVs for soil productivity and transport costs

The production zones differ in terms of their soil productivity and their proximity to population centers. In order to estimate the LUV associated with a given agricultural class for a given production zone, these factors must be included (Eqn 4).

$$\text{ALUV}_{ijk} = (\text{LUV}_k \times (\text{TDN}_j/\overline{\text{TDN}})) - (D_{jk} \times T_i) \quad (4)$$

Adjusted land use value (ALUV) was calculated for each unique combination of agricultural class (i), production zone (j) and population center (k). For each production zone, the LUV was multiplied by the ratio of the productivity (TDN) of the soils within the zone and the average productivity of agricultural soils found in NYS. This product was then discounted for transport costs by subtracting the product of the distance (D) between the production zone and population center times the transport cost per km (T) associated with a given agricultural class.

Table 1. Population of consumption zones.

Consumption zone	Population (10^6 persons)	
	Within urbanized area[1]	Within entire zone[2]
Albany	0.56	1.28
Binghamton	0.16	0.56
Buffalo	0.98	1.52
New York–Newark[3]	11.87	12.10
Poughkeepsie–Newburgh	0.35	0.86
Rochester	0.69	1.16
Syracuse	0.40	0.97
Utica	0.11	0.53
Total	15.12	18.98

[1] Includes only persons living within each individual urbanized area as defined by the US Census Bureau[35].
[2] Includes all persons within the zones demarcated in Fig. 2.
[3] 'New York–Newark' is a Census Bureau designation for the contiguous urbanized are that contains both New York City, NY and Newark, NJ. The population values reported here include only residents from NYS. To avoid confusion about whether or not the New Jersey population has been included in the analysis, this consumption zone is referred to as 'New York City' elsewhere in the text.

Euclidian distances were calculated from the geographic center of each production zone to the geographic center of each population center. Costs assume that all products are moved by truck. Estimates of truck transport costs were obtained from the USDA Agriculture Marketing Service for refrigerated agricultural products and bulk grains[36,37].

Optimization: allocating the available production potential

The optimization problem solved in the foodshed model *maximizes* the LUV derived from supplying the food needs of NYS population centers. The optimization problem was specified as a matrix of producers and consumers in which each production zone is a potential source of land for meeting the food needs of any consumption zone. The optimization software solved for the matrix of values that maximized the total ALUV throughout the study area while not exceeding the food needs of consumption zones. This function is meant to mimic the allocation of land to its highest and best use. Total ALUV (Eqn 5) was defined as the sum of the products of the area of agricultural land (A) allocated from each production zone (j) to produce food from each agricultural class (i) for each consumption zone (k) and the associated ALUVs. The value reached by the model was a *global* maximum for the entire state.

$$\mathrm{ALUV}_{\mathrm{total}} = \sum \left(A_{ijk} \times \mathrm{ALUV}_{ijk}\right) \tag{5}$$

This optimization problem was subject to two categories of constraints. The first set of constraints (Eqn 6a) required that the quantity of food (F) supplied to each consumption zone (k) be less than or equal to the need (C) of the consumption zone for a given type of food (i). These constraints prevent any consumption zone from receiving more food than it needs, while allowing the model to leave the needs of some consumption zones unmet. Note that the quantity of food supplied to a given consumption zone is the sum of the products of the area allocated by each production zone and its corresponding yield. The second set of constraints (Eqn 6b) required that the area of land (A) allocated by each production zone (j) respect the land use limitations implied by the recommended crop rotations from Equation 2. These constraints ensure that the area of land allocated to agricultural classes derived primarily from a given type of land (i) be less than or equal to that zone's potential agricultural area available for such crops (P).

$$\sum F_{ik} \leqslant C_{ik} \tag{6a}$$

$$\sum A_{ij} = P_{ij} \tag{6b}$$

Because certain agricultural classes contained both annual and perennial crops, a heuristic approach was used to represent these constraints. Namely, the estimates of land availability for annual and perennial crop production were converted into limits of land availability for 'eggs, grains and vegetables' (all annual crops) and 'dairy, fruit and meat' (primarily perennial crops). The area of land available limited to production of 'dairy, fruit and meat' was inflated to account for the fact that dairy and meat production are supported by a mix of annual and perennial crops.

Optimization was performed using the Premium Solver Platform™ v6.5 and the Extended Large-Scale LP Solver Engine v6.5 from Frontline Systems[38,39]. These programs are upgrades of the basic solver in Microsoft Excel® and are accessed through the solver dialogue box in Excel®[40,41].

Scenarios. Eleven scenarios were examined within this study, each representing a different level of receptivity to meeting dietary needs with locally sourced foods. This 'willingness' to eat a local diet refers to the acceptability of substituting a product which can be grown in NYS, such as an apple, for one which cannot be grown in the state's climate, such as a banana. In addition, 'willingness' includes consumer openness to eating foods within their windows of seasonal availability, rather than expecting year-round access. This definition of 'willingness' differs from the economic concept of 'willingness to pay' and is useful for thinking about how much dietary change would be culturally acceptable, irrespective of differences in price.

Each scenario also accounts for the fact that some proportion of current consumption is already supplied by production on New York farms. The actual 'baseline' level of local or regional food consumption is not well quantified because information on trade patterns and marketing channels for individual farm commodities is fragmentary and often non-existent. Thus, a baseline was calculated under the admittedly inaccurate, background assumption that current crop and livestock production in New York is

Table 2. Baseline 'willingness' to consume local food and incremental changes with each scenario[1].

Agricultural class	Baseline 'local' food consumption (% of food need)[2]	NYS Food need (Tg)[3]	Baseline 'willingness' (Tg)[4]	Incremental changes in 'willingness' (Tg)[5]
Grains	4.9	2.442	0.120	0.232
Vegetables	28.8	3.797	1.093	0.270
Fruit	17.0	3.154	0.536	0.262
Dairy	109.2	2.425	2.648	−0.022
Eggs	13.3	0.474	0.063	0.041
Meat	1.5	1.501	0.023	0.148
Total	32.5	13.793	4.483	0.931

[1] Scenarios vary based on the 'willingness' of consumers to consume a diet composed of entirely local foods. The baseline represents the background level of consumption of foods produced in-state. Other scenarios assume incremental shifts toward local diets. See text for more details.
[2] Baseline 'local' food consumption was estimated by dividing the estimated quantity of agricultural commodities required to meet in-state food needs by statewide agricultural production. For this calculation, food needs were expressed in quantities of primary agricultural commodities required at the farmgate. Estimates of per capita farmgate level food needs for each agricultural class came from the model described by Peters et al.[13] Agricultural production for each class was estimated from production reported in *New York Agricultural Statistics: 2006–07 Annual Bulletin*[42]. Grain production equals sum of the harvested production of wheat, rye, soybeans and dry beans. Vegetable production equals the sum of the harvested weight of fresh vegetables, processed vegetables and potatoes. Meat production equals the sum of broiler, duck and turkey production plus marketings of cattle, calves, hogs and pigs, and sheep and lambs. Summary statistics for dairy, egg and fruit production were used directly.
[3] Total food needs of NYS are equal to the total NYS population reported in Table 1 multiplied by the per capita food needs from Table 3. Values are expressed in weight of primary food commodities.
[4] The maximum quantity of food which New Yorkers are 'willing' to consume from in-state agricultural production in the baseline scenario.
[5] The incremental changes in the quantity of food New Yorkers are 'willing' to consume from in-state sources with each 10% shift from a baseline diet to a deliberately local diet.

Table 3. Per capita food needs and average yield of food products used in the foodshed model, summarized by agricultural class.

Agricultural class[1]	Food needs (kg person^{-1} yr^{-1})[2]	Food yields (kg ha^{-1})[3]
Grains[4]	129	3703
Vegetables	200	22,539
Fruit	166	14,670
Dairy	128	2016
Meat	79	427
Eggs	25	1501

[1] Agricultural classes aggregate broadly similar crop and livestock enterprises.
[2] Values for food needs represent the quantity of primary food products required to provide nutritional needs accounting for losses and inedible portions.
[3] Values shown for food yields represent the quantity of primary food products that could be produced on 'average' NYS agricultural land accounting for crop yields, livestock feed requirements and weight changes that occur in processing.
[4] The 'grains' category includes all agronomic crops used for direct human consumption: cereals, oilseeds, pulses and sugar crops. Agronomists tend to refer to these plants as 'field crops'.

not exported but used instead to meet in-state food needs. While this assumption does not reflect the actual flow of food, it does reflect the fact that a non-trivial amount of the state's food is already supplied from NYS sources, irrespective of consumer interest in local and regional food or deliberate policies to promote such interest.

According to this baseline estimate, NYS already produces a sufficient quantity of fluid milk to meet the food needs of its population, but falls short in the other agricultural classes (Table 2)[42]. Each of the other 10 scenarios represents a 10% increase in the 'willingness' of the population to consume *a deliberately local diet*. Total estimated NYS food needs and the estimated baseline consumption of NYS foods were used to determine the incremental shift in 'willingness' to consume local foods for each 10% shift toward a local diet. This could be interpreted as an additional 10% of the population completely following a local diet or the entire population following a local diet an additional 10% of the calendar year. As 'willingness' increases, a larger share of statewide food needs may be supplied by 'in-state' production, if adequate capacity is available, and if additional production increases the LUV.

Results

Food needs, food yields and LUV by agricultural class

Based on the dietary assumptions used in the model, each New Yorker requires 727 kg of primary food commodities annually (Table 3). Plant foods constitute approximately two-thirds of the diet (on a weight basis), while livestock products account for the remaining third. Land requirements for producing each agricultural class vary widely, spanning nearly two orders of magnitude. Vegetables and

Table 4. Estimated annual net returns to land and capitalized LUV for each agricultural class. Based on NYS prices, 1997–2004[1].

Agricultural class[2]	Component enterprises[3]	Net annual returns[4]		LUV[5]	
		Average land	Sensitivity to 1% change in yield[6]	Average land	Sensitivity to 1% change in yield[6]
	N	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}
Grains	3	23.54	3.44	235.38	34.40
Vegetables	14	1975.15	47.04	19,751.50	470.38
Fruit[7]	8	302.96	–	3029.56	–
Dairy	6	138.05	11.30	1380.46	113.00
Meat	9	−35.09	2.95	−350.93	29.50
Eggs	3	500.03	10.03	5000.29	100.29

[1] Complete details on the calculation of net returns and LUV for all component enterprises are reported in Peters[25].
[2] Agricultural classes aggregate broadly similar groups of enterprises. Details on the individual enterprises included within each class and their respective net annual returns and LUV are reported in Peters[25].
[3] Note that the dairy, eggs and meat classes include both livestock enterprises and the crop enterprises required to support the animals.
[4] Net annual returns to land represent the residual value after subtracting variable costs, fixed costs and the value of the operator's time and management from gross returns.
[5] LUV equals net returns to land capitalized at a 10% discount rate.
[6] Sensitivity to changes in yield assumes that gross returns are a direct function of yield whereas only some costs vary across yield levels.
[7] Data were not available on variation of fruit yields with soil type. Thus, sensitivity of returns and LUV to yield changes were not calculated.

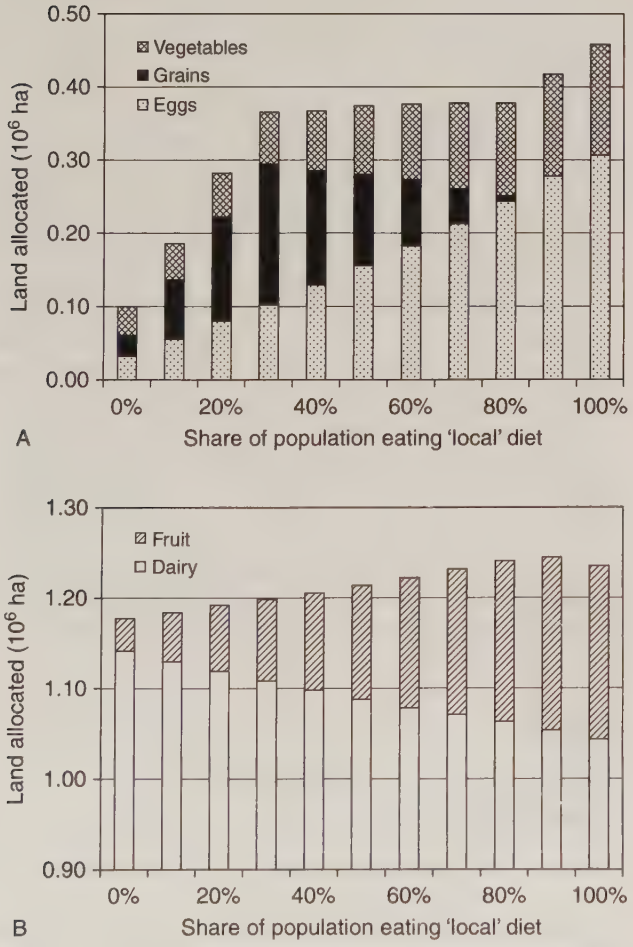

Figure 3 . (a, b). Land allocated to meet in-state food needs by agricultural class and model scenario for systems based primarily on annual cropping (a) and those based primarily on perennial cropping (b).

fruits have high yields of primary food commodity per hectare. Grains, dairy and eggs have intermediate yields. Meat products have the lowest yields.

Returns to land also differ greatly between the agricultural classes (Table 4). Vegetables were found to be the most lucrative class, with net returns and LUV is almost four times higher than the next most valuable class. Eggs, fruit and dairy classes offered more modest returns relative to vegetables. Grains and meat provided the lowest returns. Indeed, returns for the meat class were negative on land of average quality. All classes are quite sensitive to shifts in yield, with changes in LUV relatively greater than a 1% change in yield.

Allocating production potential to maximize LUV

The area of agricultural land allocated to meet the food needs of the in-state population increased as 'willingness' to eat a local food diet increased (Figs. 3a and b). Interesting differences were observed between the land available for enterprises based on 'annual' cropping (eggs, grains and vegetables) and the land available for enterprises based on 'perennial' cropping (dairy, fruit and meat). Land area devoted to 'annual' cropping increased for all classes up to the 30% scenario (Fig. 3a). However, as willingness to consume local food increased beyond 30%, the area of land devoted to grains decreased relative to eggs and vegetables and ultimately declined to zero. In addition, the majority of the 0.46 million ha of land available for grains, vegetables and eggs was used in most scenarios. In contrast, the area devoted to agricultural classes supported by perennial crop production increased gradually as willingness to eat local food increased, but never came close to reaching the total 2.7 million ha of land available for

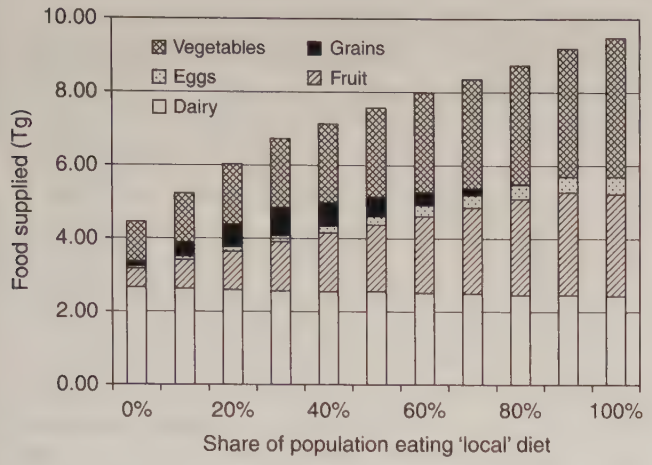

Figure 4. Food supplied by in-state production by agricultural class and model scenario.

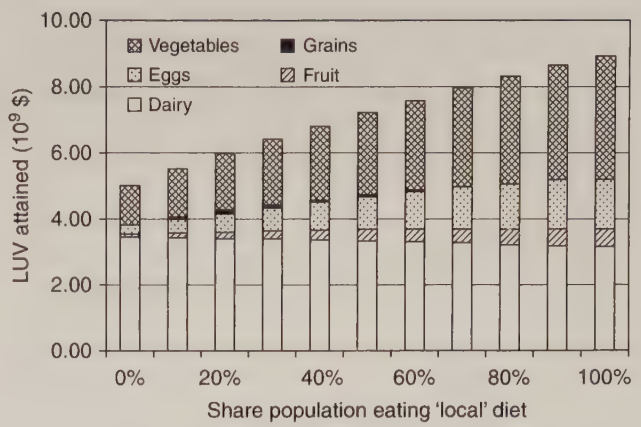

Figure 5. LUV attained from allocating agricultural to meet in-state food needs, by agricultural class and scenario.

perennial-based agriculture (Fig. 3b). Dairy occupied the largest area of any single agricultural class in every scenario.

The quantity of food supplied by in-state agricultural land increased as 'willingness' to eat local increased (Fig. 4). Values ranged from 4.5 to 9.5 teragrams (one teragram = one million metric tons) of food, as consumed on a primary food commodity basis. Dairy, eggs, fruit and vegetables were supplied in all scenarios. However, grains were supplied only in scenarios where the 'willingness' to eat local was 80% or less. No meat was supplied in any scenario.

Similar to food production, the maximum total LUV attained in each model run increased as the allowable in-state consumption increased (Fig. 5). The total LUV ranged from 5.0 to 8.9 billion dollars. Dairy accounted for the vast majority of the LUV in the baseline scenario, but its share of LUV decreased relative to eggs, fruit and vegetables as the scenarios allowed for a greater share of consumption to be 'local'. Grains, where present, constituted a very minor share of total LUV.

Mapping foodsheds by agricultural class

Potential local foodsheds were mapped by agricultural class (Figs. 6a–d). Given the large number of scenarios, results are reported only for the 100% local-food scenario. This scenario was selected because it can be compared to earlier work that also mapped foodsheds for 100% local diets[16]. While the spatial extent of the area devoted to each agricultural class is different, the spatial dispersion of each foodshed is similar across agricultural classes. Consumption zones near the map edge (Buffalo, Rochester and Syracuse) generally received food from nearby land. However, zones closer to New York City (Albany, Binghamton, Poughkeepsie-Newburgh and Utica) display a 'ray-like' pattern. The foodshed for New York City extends throughout the state.

Potential food production was distributed almost directly in proportion to population (Table 5). New York City received a slightly lower share of total food needs than the seven consumption zones located in 'upstate' New York. In contrast, the 'food distance traveled' for the New York City foodshed was much greater than those of the other consumption zones. Overall, 69% of total statewide food needs were met in the 100% local scenario, while the average food distance traveled was 238 km.

Discussion

The primary goal of this study was to evaluate and map the potential to supply food locally by food groups. Since agriculture tends toward specialization, the model requires a method for deciding which foods should be produced locally. LUV was chosen because it has been proven empirically to influence land use decisions. Although the findings are foremost a proof of concept, they illustrate some key principles worthy of consideration in the broader discussion of local and regional food systems. In addition, the results have implications for the development of local and regional food systems in NYS.

Key principles

One principle illustrated by the findings is that of highest and best use. This was most clearly demonstrated by the allocation of agricultural land. The reduction in land devoted to 'grain' at scenarios greater than 30% willingness to eat local food was the result of displacement by higher value eggs and vegetables. Indeed, land was only dedicated to the lower value grains class if the 'demands' for all higher value classes were already satisfied and suitable land was still available. Thus, while the potential markets for locally or regionally sourced foods is not known with any certainty, the results are a reminder that land tends to be devoted to the most valuable use possible.

A second principle illustrated by the model is that of marginal land. In all scenarios, large areas of land were not used by the model. Given the objective function, this result means that this land could not produce an economically viable (i.e., positive) return without reducing the total LUV.

Table 5. Food needs satisfied and food distance traveled in 100% local scenario.

Foodshed	Food need (Tg)	Food supplied (Tg)	Food need satisfied (%)	Total food distance[1] (Tg-km)	Average food distance[2] (km)
Albany	0.93	0.66	71.4	80	120
Binghamton	0.41	0.29	71.4	48	164
Buffalo	1.11	0.79	71.4	34	43
New York City	8.80	5.92	67.3	1982	335
Poughkeepsie—Newburgh	0.62	0.44	71.4	55	123
Rochester	0.84	0.60	71.4	21	35
Syracuse	0.70	0.50	71.4	21	42
Utica	0.38	0.27	71.4	18	67
All consumption zones	13.79	9.49	68.8	2259	238

[1] Food distance equals the quantity of food supplied from a production zone to a consumption zone multiplied by the distance between those zones. Total food distance is the sum of the food distances for all production zones serving a consumption zone (or group of zones).
[2] Equals total food distance divided by food supplied.

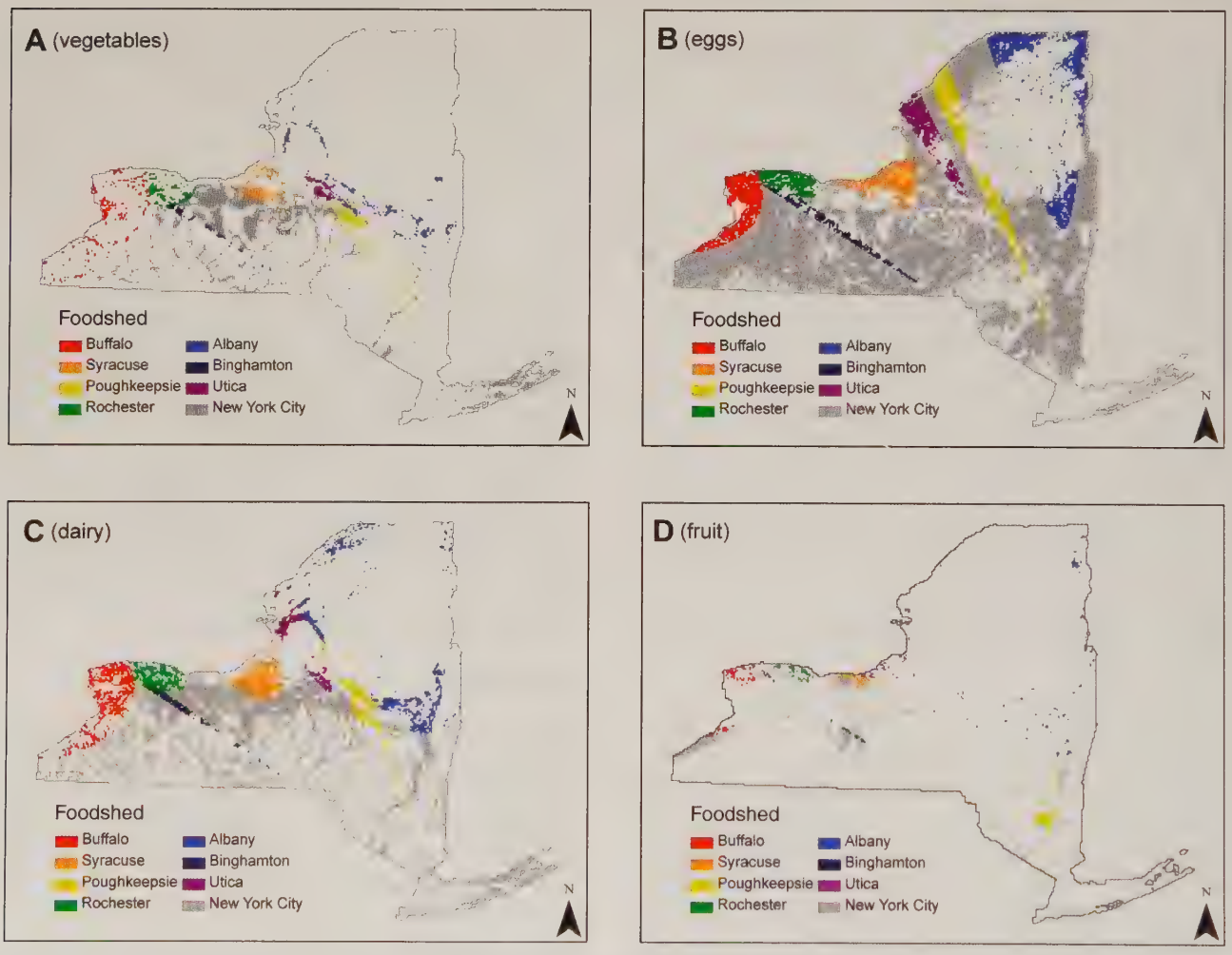

Figure 6. (a–d) Production zones allocated to meeting in-state food needs for the 100% local scenario, by consumption zone and agricultural class: (a) vegetables, (b) eggs, (c) dairy and (d) fruit.

This land may have had uses for which returns were positive. Indeed, vegetable production was estimated to produce positive returns on many types of land. However, the better (more productive) land was used first, leaving marginal land behind. This is consistent with the land use history of NYS, in which large areas of land were abandoned from farming over the course of the 20th century[43]. However, the model makes this determination based on a single factor (LUV), whereas farmland use decisions in reality are multi-factorial. They incorporate, for example, attitudes toward risk, availability of agricultural support services and non-economic land ownership

goals. Nonetheless, the model illustrates an important point: not all technically available land will be used for food production.

Implications for NYS

Beyond these general principles, the findings raise several issues regarding the capacity for increased reliance on local and regional food in NYS.

First, local and regional food systems will specialize in production of certain foods. The model illustrates that in NYS, competition for the highest and best agricultural use of land would favor production of dairy, eggs, fruit and vegetables relative to grains and meat. This is consistent with what one would expect based on the LUV estimates, and in a general sense, it reflects actual land use patterns in New York. Fruits and vegetables combined constituted 56% of the 1.75 billion dollars of crop production generated in 2007, and dairy constituted 86% of the 2.76 billion dollars of livestock and poultry production for the same year (authors' calculations from *New York Agricultural Statistics, 2008-2009 Annual Bulletin*)[44]. Thus, increasing local food generally means growing more of the things the state already produces.

Second, specialization could enable local and regional food systems to supply a large share of the state's food needs. The model shows that up to two-thirds of statewide food needs, on a fresh weight basis, could be supplied by agricultural land in the state. In contrast, an earlier study of NYS that examined the capacity to provide complete diets found that the state could supply approximately one-third of its food needs[16]. This finding results directly from the fact that the LUV-based model favors high-value enterprises which are, coincidentally, also water rich. Therefore, a larger share of the *mass* of food could be supplied than when foods were produced in proportion to nutritional needs. This suggests that food miles might be reduced strategically by focusing on the water-rich foods with relatively high yields per acre, such as most fruits and vegetables.

Third, the model suggests that local and regional food systems would focus on supplying certain foods rather than certain cities. Our earlier work minimized food miles, and the model allocated food preferentially to cities in upstate New York at the expense of New York City. In contrast, the productive capacity of New York's agricultural land was more equitably distributed in the differentiated food group model. While the food miles based model can provide an estimate of the theoretical minimum distance food would need to travel, the LUV-based model is probably more realistic.

Directions for further research

One modification that would enhance the value of this model is to allow land to be allocated to food 'exports.' In such a scenario, the NYS population would 'compete' with the larger US population for foods produced on in-state agricultural land. For example, the use of land for production of fluid milk to supply the New York City foodshed might compete with demand from New Jersey. Such an approach would help to shed light on the question of where local and regional food systems fit in a system where national and international distribution of food predominates.

Conclusions

Models represent a simplified version of reality, but they can be valuable for gaining insight into how systems function. The LUV-based foodshed model shows that an optimal local and regional food system in NYS would specialize on high-value crops and livestock. Since these products can be produced in a relatively large volume on a relatively small acreage, a focus on fruits, vegetables, dairy and eggs could enable the state to supply a large share of total food needs (on a fresh-weight basis). These findings suggest local and regional food systems have great potential for expansion and supplying a larger share of nutritional needs. However, it remains unclear as to how much of this potential will be realized.

The principles of highest and best use and marginality of land are long lived in the literature, and LUV serves as a reasonable optimizing parameter for understanding allocation of land. However, a much broader spectrum of societal concerns motivates public interest in local and regional food systems. Future work should examine how well a strategy of focusing on high-value crops and livestock serves other important goals for the food system, such as supporting small- and medium-sized farms, reducing greenhouse gas emissions and improving access to foods lacking in the American diet. Such efforts will help to create an informed and comprehensive vision of the ideal local food system.

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Potential and limitations of organic and fair trade cotton for improving livelihoods of smallholders: evidence from Central Asia

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Abstract

Cotton is a leading agricultural non-food commodity associated with soil degradation, water pollution and pesticide poisoning due to high levels of agrochemical inputs. Organic farming is often promoted as a means of addressing the economic, environmental and health risks of conventional cotton production, and it is slowly gaining ground in the global cotton market. Organic and fair trade cotton are widely seen as opportunities for smallholder farmers to improve their livelihoods thanks to higher returns, lower input costs and fewer risks. Despite an increasing number of studies comparing the profitability of organic and non-organic farming systems in developing and industrialized countries, little has been published on organic farming in Central Asia. The aim of this article is to describe the economic performance and perceived social and environmental impacts of organic cotton in southern Kyrgyzstan, drawing on a comparative field study conducted by the author in 2009. In addition to economic and environmental aspects, the study investigated farmers' motivations toward and assessment of conversion to organic farming. Cotton yields on organic farms were found to be 10% lower, while input costs per unit were 42% lower; as a result, organic farmers' cotton revenues were 20% higher. Due to lower input costs as well as organic and fair trade price premiums, the average gross margin from organic cotton was 27% higher. In addition to direct economic benefits, organic farmers enjoy other benefits, such as easy access to credit on favorable terms, provision of uncontaminated cottonseed cooking oil and cottonseed cake as animal feed, and marketing support as well as extension and training services provided by newly established organic service providers. The majority of organic farmers perceive improved soil quality, improved health conditions, and positively assess their initial decision to convert to organic farming. The major disadvantage of organic farming is the high manual labor input required. In the study area, where manual farm work is mainly women's work and male labor migration is widespread, women are most affected by this negative aspect of organic farming. Altogether, the results suggest that, despite the inconvenience of a higher workload, the advantages of organic farming outweigh its disadvantages and that conversion to organic farming improves the livelihoods of small-scale farmers.

Key words: organic cotton, fair trade, livelihoods, economic performance, impact, Kyrgyzstan

Introduction

Cotton is one of the leading agricultural non-food commodities and ranks among the top consumers of agrochemicals. Accounting for 16% of insecticide releases, it exceeds all other major crops in terms of insecticide application[1]. Insecticides are responsible for a large proportion of acute and chronic health problems associated with the use of agrochemicals, representing 52% of those classified by the World Health Organization as extremely, highly or moderately hazardous. Many insecticides are designed to interfere with the physiology of pest species, that is, their nervous and reproductive systems. These chemicals are particularly hazardous as they can also affect human and animal health. Pesticides applied to cotton can potentially contaminate cottonseed oil and cottonseed derivatives fed to livestock, thereby entering the food chain[1,2]. As such, serious environmental and health risks are linked to conventional production of cotton. It is increasingly associated with problems such as soil fertility loss, water pollution and pesticide poisoning[1–5]. Cotton is mainly produced in developing countries: 99% of the world's cotton farmers live in such countries and produce 75% of the world's cotton[1]. The majority are small-scale, resource-poor farmers who

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cultivate cotton as a cash crop. Production bears inherent economic risks that are further compounded by rising input costs for fertilizers, fuel and pesticides as well as by low cotton prices due in part to highly subsidized production and export in the USA and the EU[6–8], fluctuating yields[9] and volatile world markets. Widespread indebtedness among conventional smallholding cotton farmers has led some, notably in India, to commit suicide[10].

In the late 1980s, non-governmental organizations began promoting organic farming as a means of addressing the economic, environmental and health risks of conventional cotton production[9]. The main difference between conventional and organic cotton production is that organic farmers avoid the use of chemicals, synthetic fertilizers, synthetic pesticides, herbicides, growth promoters or genetically modified organisms. Organic farmers' methods of nutrient management include crop rotation, intercropping and the use of compost and farmyard manure. Pest management is mainly based on preventive measures, crop rotation and the use of botanical pesticides[2,9].

In recent years, growing consumer interest in 'green' products has expanded organic cotton's share of the global cotton market; an increasing number of brands and retailers—mainly American and European—have launched or enlarged their organic cotton textile programs[11–13]. Between 2001 and 2009, the average annual growth rate of global retail sales of organic cotton products was 40%[13]. According to the estimates of Ferrigno et al.[14], in 2009 approximately 220,000 farmers—the majority of them smallholders—cultivated organic cotton on about 253,000 ha of land spread between 22 countries worldwide. Nevertheless, despite such impressive growth rates and global reach, organic cotton still only represents 0.76% of worldwide cotton production. The biggest players in the organic cotton trade are India, Turkey and Syria, who account for about 90% of global production combined. By contrast, Kyrgyzstan's share of global organic cotton production amounted to a modest 0.24% in 2008–2009[14].

Although—or perhaps because—organic cotton is a niche market, its production is increasingly seen as an opportunity for smallholding farmers in developing countries to improve their livelihoods based on higher returns and reduced economic, environmental and health risks. This view is supported by the growing market demand and the results of a number of studies on the profitability of organic cotton in Sub-Saharan Africa and Asia[7,9,15–17].

Despite an increasing number of studies comparing the profitability of organic and non-organic farming systems in different developing and industrialized countries, little has been published on organic farming in Central Asia. The present article investigates the performance of certified organic cotton production in southern Kyrgyzstan and compares it to conventional cotton production in the same region. Specifically, it examines the economic and social impacts of organic cotton production and perceived changes in soil qualities. In addition, it investigates small-scale farmers' motivation to convert to organic farming and the potential and limitations of organic farming to improve their livelihoods.

Organic and Fair Trade Cotton in Jalal-Abad Province

Cotton dominates the export market of most Central Asian countries, where it is cultivated as a monoculture with important environmental, social and political consequences[18]. Although much less important in Kyrgyzstan, relative to other Central Asian countries, cotton still made up about 25% of Kyrgyzstan's total agricultural export receipts between 2004 and 2007[6].

In 2004, with support from the Swiss State Secretariat of Economic Affairs (SECO) and the Dutch Interchurch Organisation for Development Cooperation (ICCO), the Swiss NGO Helvetas initiated organic cotton production in Jalal-Abad province, located in southern Kyrgyzstan's cotton-growing region. Known as the BioCotton Project, it began with 58 farmers. In the following years, impressive growth rates were observed in terms of the number of contracted farmers and the surface area of organic production. By the end of 2009, 765 organic farmers—including 420 officially certified—were contracted and organized into farmer groups. They cultivated a total of 1198 ha of land, 312 ha of which were reserved for organic cotton (source: Internal control system BioService Foundation). Compliance with organic standards (EU regulation 834/2007) was and is monitored by an internal control system and verified by an internationally accredited certification agency, the Institute for Marketecology (IMO) control, Switzerland. The process through which farmers' transition from in-conversion to certified organic status takes 3 years.

In 2007, two supporting institutions with complementary roles were founded in Kyrgyzstan: the BioFarmer Cooperative and the BioService Foundation. The main functions of the BioFarmer Cooperative, of which all local organic farmers are members, are organizing production (including provision of inputs) and processing, promoting organic farming, organizing farmers and lobbying. The BioService Foundation provides services to organic farmers such as training and consultation, internal control systems and marketing.

In 2004, Fairtrade Labelling Organizations International (FLO) established fair trade standards for seed cotton. Although it may not change the fundamental inequities and power relations in the existing commodity chains[19], fair trade adds a social and development perspective[7]. Fair trade is based on paying producers a guaranteed minimum price that varies according to the production context of each country. That minimum must be high enough to cover production costs and the producer's living expenses as well as the costs of registration, auditing and certification by the fair trade inspection body FLO-Cert. In addition to the minimum producer price, a premium is paid to the producer organization, namely, the BioFarmer Cooperative for

communal development projects. Smallholders participate in fair trade through membership-based producer organizations, which are audited by FLO-Cert to guarantee compliance with fair trade standards[20]. The BioFarmer Cooperative obtained fair trade certification in 2007 and received its first fair trade premium in 2008. Thus, certified organic farmers in the region now receive both organic and fair trade premiums for their cotton.

Research Approach and Methods

The impacts of the BioCotton Project were assessed in a field study in 2009[21]. The study focused on economic performance as well as the perceived social and environmental impacts of organic farming. The research approach was a twofold comparison: (a) comparing certified organic farmers to a control group of conventional farmers (systems comparison); and (b) comparing the organic farmers' situation before the start of the project to that in 2009, set against the general development of the control group's situation (time comparison). The study was carried out between June and October 2009, that is, during the 2009 cropping season. As such, crop production data belong to the 2008 agricultural year.

To compare organic farming with conventional farming practices, seven villages were selected according to the following criteria: high-enough number of certified organic farmers, equal representation of production zones and exclusion of villages with 100% organic farmers. The sample included 44 certified organic and 33 conventional farms. Organic farmers were randomly selected for interviews from the database belonging to BioService's internal control system. By contrast, conventional farmers had to be selected for interviews via convenience sampling (i.e., farmers readily available and convenient), since no lists were available and there was not enough time to compile such lists, and because it is scarcely possible to meet a specific individual without an appointment.

Data were mainly collected via questionnaire-based interviews with farm managers. Focus group discussions and expert interviews were used to clarify and deepen specific questions and emerging issues based on analysis of questionnaire data. To share and validate results, a validation workshop was held with representatives of different stakeholder groups, including organic and conventional farmers, extension agents, project staff and representatives of the BioFarmer Cooperative and the ministry of agriculture. The questionnaire covered quantitative aspects of agricultural production as well as the respondent's perception and assessment of observed changes in economic, social or environmental areas.

A number of difficulties were encountered during fieldwork. The most important were: (1) lists of (conventional) farmers were unavailable; (2) many conventional farmers had stopped cultivating cotton in 2008 due to unfavorable cotton prices and input prices, making it impossible to find equal-sized comparison groups in every village and leading to differences in sample sizes; and (3) the majority of farmers did not keep detailed records of production data. The researchers therefore had to rely on recall of data, which is prone to uncertainties.

Data Processing and Statistical Analyses

Statistical analyses were conducted using the program SPSS (SPSS Inc., Chicago, Illinois, USA). Due to the inherent limitations of recall data in terms of reliability, the data were basically analyzed with descriptive statistics. *t*-tests were used to test for significance of mean differences regarding household characteristics, perceptions of changes in workload and a global-scale assessment of the development of cotton production. Sex-disaggregated analyses were not viable, as the number of female farm managers was too small in both samples.

Results and Discussion

Given the organic cotton initiative's short duration of implementation in Kyrgyzstan—6 years—at the time the field study was conducted, the results presented here suggest short-term impacts of the BioCotton Project and cannot be used to determine the overall long-term viability of organic cotton production in the area.

Characteristics of small-scale cotton farming in Jalal-Abad

The organic and conventional farms surveyed did not significantly differ regarding basic household characteristics such as education level, sex and mean age of farm managers, ethnic group or family size. Depending on the village, respondents were either ethnic Kyrgyz or Uzbek. Over 80% of the farm managers who participated in the study were men. Only 11% of the organic farms in our sample were managed by a woman, in contrast to the 25% share of female farm managers counted by the BioCotton Project in 2009. This difference likely stems from the fact that our study only included certified organic farms, those run by farmers who joined the project in its initial years from 2004 to 2006, a time when organic farming was new to the area and men overwhelmingly pioneered.

Participants' land holdings were small: 68% of the organic and 76% of the conventional farmers in our study had less than 1 ha of irrigated land (mean: organic 1.07 ha, conventional 0.84 ha). Cotton, in addition to most other crops, is only produced on irrigated land. Other than cotton, the most important crops in the region are wheat, rice, maize, alfalfa and sunflower, used mainly for personal consumption or as animal feed. The majority of farmers in our study cultivated less than 0.5 ha of cotton (Fig. 1). While the requirements of organic farming limit the use of cropland for cotton to 50% of available land, conventional farmers are not subject to any such restrictions.

Farming was a key source of income for the respondents in our study, though not necessarily the most important. On

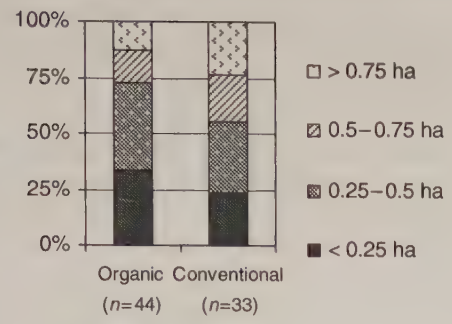

Figure 1. Area under cotton 2008 (ha).

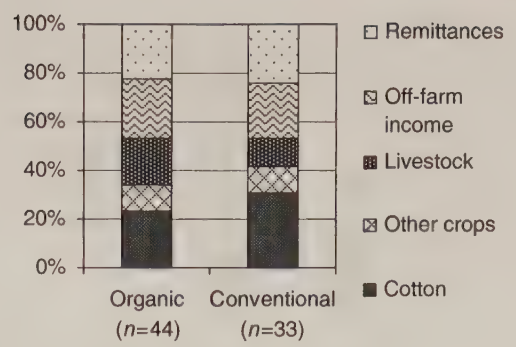

Figure 2. Average shares of household income in organic and conventional farms in 2008.

average, both the organic and conventional farming households surveyed derived half of their income from farming (53%) and half from off-farm activities (47%). In terms of the source farming income, the main difference between organic and conventional farming households was the relative importance of cotton and livestock (Fig. 2). Cotton was more important in the household budget of conventional farmers, in particular because they have no restriction on the area they may use for its cultivation. Livestock were more important for organic farmers than conventional farmers. Many more organic farmers (43%) than conventional farmers (19%) reported increasing the number of livestock they kept over the previous years. Organic farmers kept more livestock for the following reasons: first, manure from the livestock could be used as fertilizer; secondly, they were less likely to sell their animals for cash in times of need since their participation in the BioCotton Project provided them access to lines of credit for agricultural production; thirdly, they could obtain the cake of pressed cotton seeds for use as animal feed at no extra cost, in contrast to conventional farmers who must buy some of their animal feed.

For 7% of the organic farmers surveyed and 18% of the conventional farmers surveyed, off-farm income—such as remittances, salaries, business activities and pensions—accounted for more than 75% of total household income. Remittances are an important economic factor in southern Kyrgyzstan: 52% of the organic farms and 52% of the conventional farms surveyed had someone working abroad, usually young men. While labor migration and off-farm activities have positive economic effects, they limit the availability of labor for agricultural work, of particular relevance for organic farming. Slightly more adults (age $\geqslant 16$) worked full time on-farm in organic farming households (mean: 2.50 adults) when compared with conventional farming households (mean: 2.27 adults). In general, more women than men were found to work full time on-farm.

Why do farmers convert to organic farming?

A range of perceived advantages were found to motivate farmers to convert to organic farming, including: higher market prices for organic cotton (premiums), reduced costs for agricultural inputs, services provided by support organizations (e.g., access to credit, provision of seeds, marketing support, training, returning the cotton oil and press cake after ginning), reduced health risks and soil improvements. Most of the reasons for conversion cited by respondents could be characterized as economic. Similar economic motivations for conversion to organic farming have been found among smallholding coffee growers in Latin America[22], cotton growers in Africa[23] and farmers in Asia[24].

In general, the organic farmers interviewed were very conscious of the benefits of organic farming and the valuable support they received from BioService and the Cooperative. They assessed their previous decision to go organic—made several years earlier—in correspondingly positive terms: When asked what they would do if faced with the same decision today (2009), 91% stated they would convert to organic farming again. Twenty-seven percent of the organic farmers went as far as to say that they would not switch back to conventional farming under any circumstances. Interestingly, the majority of conventional farmers interviewed stated that they had considered converting to organic, but were deterred by aspects of organic cotton farming—real or perceived—such as the high labor input required, the requirement of crop rotation and the small size of their plot, lower yields, insufficient knowledge and a lack of livestock to produce the amounts of manure necessary.

Economic impact of organic cotton

As it was purely recall data and fraught with uncertainty, the study's production-related data do not enable definitive, in-depth quantitative economic analyses. Nevertheless, triangulation with qualitative data provides enough evidence to support the following conclusions regarding the profitability of organic cotton farming.

The certified organic farmers interviewed harvested an average of 2600 kg cotton per hectare in 2008, compared to 2900 kg per hectare harvested by the neighboring conventional farmers who were interviewed (basis: recall data). Thus, the production level of organic cotton farming was 10% below conventional cotton farming. Similar to the results reported by organic farmers in India[15], most of the organic farmers interviewed observed an initial decrease in cotton yields in the first 2 years after their conversion to

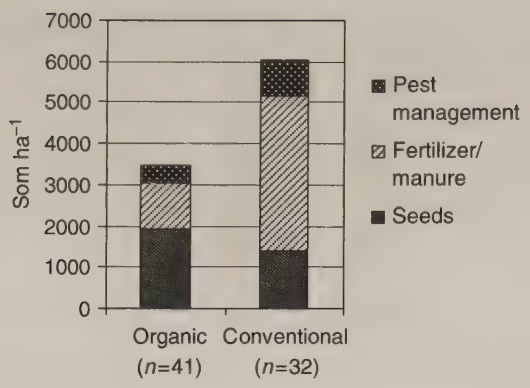

Figure 3. Input costs 2008 (Som ha^{-1}).

organic. However, according to their statements, their yields steadily increased each year after the initial 2-year post-conversion period, yet generally remained below the yield levels of conventional production. The interviewees identified crop rotation as a major cause of their initial decrease in yields. Due to the occasionally limited availability of manure and considerable labor input required many farmers initially only applied manure on areas where cotton was grown. Thus, in the second year following their conversion to organic farming, cotton was sown on land that was not fertilized with manure the previous year. Third-year stabilization of yields—though possibly still below the levels of conventional production—have been reported elsewhere by the International Fund for Agricultural Development (IFAD)[24] and others[2]. In addition to the dynamics of crop rotation, factors such as farmers becoming more experienced in organic farming and the general effects of soil restoration may also contribute to gradual increases in yields following the initial 2-year post-conversion period[2,7,15,25,26].

The organic farmers interviewed spent 42% less on agricultural inputs (Fig. 3). Although they paid more for seeds, they invested little money in pest management or fertilizer, as no non-organic inputs are allowed and few external inputs were purchased. The organic farmers who received manure from other farms were usually given it free of charge. At the time of the field study in 2009, the exchange rate of Euro to Som was approximately 1 : 60.

The prices of fuel and machinery rentals have increased markedly in recent years, in particular between 2007 and 2008[27]; this affects both organic and conventional farmers. However, conventional farmers suffer more due to spikes in prices for agricultural inputs such as fertilizer, herbicides and pesticides. These price dynamics were reflected in the way respondents judged the development of production costs in the years leading up to our survey. Every second organic farmer perceived their production costs to be lower in 2008 when compared with the period prior to their conversion. This was almost unanimously attributed to the fact that organic farming eliminates purchases of fertilizer and agrochemicals. In contrast, 90% of the conventional farmers interviewed complained that their production costs had increased compared to 3 or 4 years before. The research methodology used did not enable collection of precise data on labor inputs or costs incurred due to rental of agricultural machinery. However, most farmers agreed that organic farming is more labor intensive than conventional farming. Following conversion, 60% of the organic farmers interviewed noted an increase in their workload; they mainly attributed the labor increase to the use of manure and compost, which must be transported to the fields and spread manually. Thus, labor costs appear to be higher in organic farming. However, precise quantification was not possible on the basis of our data.

Organic farmers in the study area may sell their cotton at a fixed price agreed upon by the BioFarmer Cooperative and international buyers. Prices of conventional cotton fluctuate considerably from month to month and may vary greatly depending on whether the cotton is sold right off the field to businessmen or to a ginnery following harvest. The value of organic seed cotton shown in Table 1 is the value after deducting the fees for services provided by the BioService Foundation (e.g., organic certification and marketing) and membership fees of the BioFarmer Cooperative. These costs amounted to 6.52 Som kg^{-1} in 2008. Thus, in 2008 the price paid for organic cotton was 26.89 Som kg^{-1}, which was 9.8% higher than the average price paid for conventional cotton in the same year.

Twice as many organic farmers (58%) as conventional farmers (29%) perceived an increase in the prices they received for their cotton in the years leading up to the survey. Conventional farmers frequently complained of declining cotton prices. Although prices had not decreased in absolute terms (see Table 1), they had in relative terms, as inflation was high in the study area—about 25% in 2008[28]. Thus, the cost–benefit ratio of cotton production was worsening, something the conventional farmers felt acutely due to their dependency on agrochemicals.

Organic farmers' revenue from cotton was 20% higher (85,774 Som ha^{-1} compared to 71,102 Som ha^{-1} in 2008). Revenue from cotton was calculated on the basis of yields and the average market value of cotton (including the organic price premium) but without considering rotation crops. In 2008, the difference in gross margin (calculated on the basis of the revenue minus input costs) was 27% in favor of organic cotton (Fig. 4).

While the study's data on labor costs and machinery costs are not sufficient to support definitive conclusions, the author's interviews led her to believe the following: labor costs in the study area were likely higher for organic farmers than conventional farmers, while organic farmers may have incurred less costs for rental of agricultural machinery, precisely because organic farming relies more on manual labor (e.g., fertilizing, weeding and pest management). However, many conventional farmers also described facing difficulty in gaining access to agricultural machinery due to its general unavailability, a fact confirmed by the Food and Agriculture Organization and the World Food Programme[27]. As such, many conventional farmers in the

Table 1. Development of cotton prices 2006–2009.

	Organic (value in Som kg^{-1})[1]					Conventional (Som kg^{-1})
	Seed cotton[2]	Cotton oil/cake	Cotton linter	Fair trade premium	Organic and fair trade cotton (total value)	Conventional cotton (average market price)
2006	16.50	4.20	0.61	–	21.31	15.50
2007	20.80	8.56	0.84	–	30.20	23.00
2008	20.37	9.25	0.99	2.47	33.02	24.50

[1] At the time of the field study in 2009, the exchange rate of Euro to Som was approximately 1 : 60.
[2] Fees for services provided by the BioService Foundation, certification costs and BioFarmer Cooperative membership fees have already been deducted (these costs amounted to 6.52 Som kg^{-1} in 2008).
(Source: Compiled by BioService Foundation, 2009, pers. comm.)

study area also relied on manual labor, possibly resulting in minimal differences between the two farming systems in terms of costs incurred for rental of agricultural machinery.

To measure the development of cotton production over time, the researchers created a global-scale assessment of cotton production that includes cotton yields, production costs, cotton prices and revenues. Internal consistency for this global scale was satisfactory (Cronbach's Alpha = 0.7). Organic farmers' assessment was more positive than that of conventional farmers. Statistical analysis (*t*-test) showed that this mean difference was significant ($P < 0.001$).

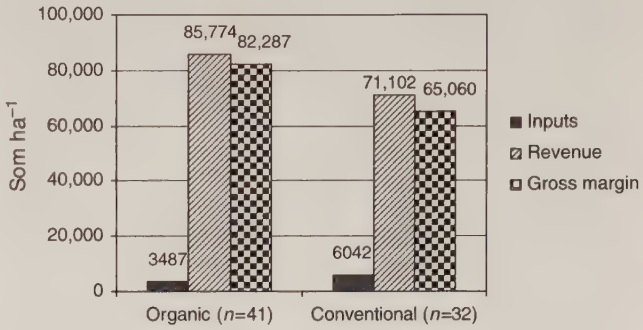

Figure 4. Gross margin 2008 (Som ha^{-1}).

Other economic benefits

The economic benefits of organic cotton production extend beyond mere revenue increases from the cotton itself. The organic cotton farmers in the study area also received valuable cotton by-products such as cotton oil for human consumption and cottonseed cake as animal feed. In addition, the organic farmers were afforded lines of credit on favorable terms, marketing assistance and access to other support services. The microcredit sector in Kyrgyzstan has grown in recent years. Yet, conventional smallholder farmers continue to face difficulty in gaining access to loans—interest rates are generally high for them and they often lack the necessary collateral[27]. Of the organic farmers interviewed, 84% claimed to have access to credit if they needed it. In contrast, only 58% of the conventional farmers interviewed claimed to have such access. Nevertheless, many of the respondents stated they were uninterested in taking out loans—even if they had access—due either to religious reasons or to fears of indebtedness.

Each of the added economic benefits enjoyed by organic cotton farmers in the study area are described in greater detail below.

Access to credit. The BioFarmer Cooperative collaborates with the microfinance institution *Agrokreditplus* to provide organic farmers with easily accessible lines of credit on favorable terms, for use in agricultural activities. The loans are secured by social collateral. Easy access to credit was a major reason as to why organic farmers in the study area were able to increase the number of livestock they held; in contrast to conventional farmers, they were not forced to sell their animals for cash in times of urgent need.

Marketing support. Collection, delivering and marketing of organic cotton is organized by the BioFarmer Cooperative. The cooperative also negotiates terms of sale with an international client, who in 2008 was a single buyer in Germany. Thus, organic farmers in the area had a *de facto* guarantee for selling their cotton at a fixed premium price. In contrast, conventional cotton farmers were forced to organize their own marketing; some sold to nearby ginneries while others sold directly to businessmen right off the farm. Unlike the organic farmers, the conventional farmers were very exposed to fluctuations in the global price of cotton.

Extension and support services. The BioService Foundation provides agricultural extension services and training to organic farmers. These were highly appreciated by the organic farmers interviewed. In contrast, conventional farmers in the study area only received limited and sporadic support from the government, for example, in cases of severe climate-related difficulties; they cannot rely on continually functioning governmental extension and support services, either because these do not exist or—as other studies suggest—because the farmers are not aware of the government services available to them[29].

Provision of cotton seeds. Organic farmers in the study area were provided cotton seeds from a seed fund. The seeds were essentially given to them as an

interest-free loan, as the costs of the seeds were only deducted once they received the cotton oil and cake the following winter.

Ecological impact

Almost all of the organic farmers interviewed perceived positive impacts of organic farming on the fertility and water-holding capacity of their soils (Table 2).

They attributed improvements in the water-holding capacity of soils almost exclusively to the use of manure. They also credited the use of manure with increasing the fertility of their soils, in combination with the introduction of crop rotation, cultivation of alfalfa, and discontinuing use of agrochemicals. In addition to fertilizing using manure, the organic farmers produced and applied compost. The organic farmers also suggested that the manure had positive effects on the structure of soils, reducing their workload as the soils became softer and easier to work. As the researchers made no soil analyses or measurements, the organic farmers' perceptions of improved soil qualities could not be confirmed. However, it is known that proper organic management builds up soil organic matter and increases populations of soil organisms[2], thereby improving soil qualities; similar positive soil effects have been reported by a number of studies from different regional contexts[9,7,24]. Finally, the organic farmers claimed that crop rotation and the use of manure generally had a positive effect on the occurrence and management of pests and diseases.

In contrast, the conventional farmers interviewed generally perceived deteriorating soil qualities over the years; only a few observed improvements, which they usually attributed to the use of manure. They attributed decreases in soil fertility to a total lack or an insufficient amount of manure and the (excessive) use of chemicals or fertilizers. Some respondents noted that their soils appeared to require more fertilizer with each year. This could possibly be due to a combination of the following factors: (a) decreasing soil organic matter content—on average, the conventional farmers interviewed used a bigger share of their available manure for fuel and 14% did not use manure as a fertilizer at all, while 79% did not produce compost; (b) limited availability of manure; and (c) nutrient depletion, as 42% of the conventional farmers who responded did not practice crop rotation.

Social impact

After economic benefits, improved health conditions were the second-most perceived positive change cited by organic farmers. They attributed health improvements to their consumption of what they subjectively considered healthier foods as well as to their reduced exposure to hazardous agrochemicals, which they no longer applied to their fields. In connection with health aspects, they again emphasized the importance of the organic cottonseed oil and the organic seed cake that they received as an in-kind payment for processing their cotton. Even conventional farmers pointed to this advantage of organic farming. While there is no proof of safer, higher-quality food being produced by organic farmers in the study area, there is evidence for the risk of food contaminated by pesticide residues in the case of conventional farming nearby[1,2]. Soviet-era cotton production in the region was characterized by the use of highly toxic pesticides, some of that are still being used in neighboring Uzbekistan; pesticides that are currently banned in Kyrgyzstan are regularly smuggled in from Uzbekistan illegally[1]. The distance of the study area to the Uzbek border ranged between 10 and 40 km. Thus, considering the problem of these dangerous pesticides could apply to conventional cotton farming in the study area, the organic farmers' perception might be interpreted as an expression of relief over having reduced their risk of consuming foods contaminated by toxic pesticides.

Table 2. Perception of changes in soil qualities over the past few years (percentage of farmers).

	Improved	The same	Declined
Soil fertility			
Organic	95%	5%	0%
Conventional	16%	39%	45%
Water-holding capacity of soils			
Organic	88%	12%	0%
Conventional	10%	49%	41%

In southern Kyrgyzstan, widespread labor migration of men increases the workload of women independent of the farming system used. Nevertheless, 60% of the organic farmers interviewed reported that the conversion to organic farming had increased their workload in the years leading up to the survey. Organic farmers perceived a higher increase in workload—overall farm workload, workload for cotton and women's workload—than that perceived by their colleagues using conventional farming methods. Again, this mean difference proved statistically significant ($P < 0.05$). Independent of the production type, more women than men perceived an increase in their workload. The perception of workloads did not differ much between men and women on conventional farms. In contrast, men's and women's perception of the workload differed greatly on organic farms. The vast majority of female respondents from organic farms (farm managers or wives) perceived higher workloads. It was generally agreed that organic farming requires more manual work, is more labor intensive, and that women in particular must bear the negative effects because (a) manual work is typically done by women, and (b) the work-related outmigration of men has left more work to women in general. Indeed, the biggest negative impact perceived by respondents in regards to organic farming—an increased workload—appeared to affect women the most.

Many more organic (53%) than conventional (30%) farmers perceived improved cooperation between farmers. The cooperation appeared to occur mainly within the

community of organic farmers. For example, the organic farmers exchanged experiences, advice and consultation and shared agricultural machinery. Organic farmers cited the BioCotton Project as the main reason behind such improvements; its frequent meetings were perceived as uniting the (organic) farmers and fostering cooperation. According to some respondents, cooperation often began among organic farmers, then spread to conventional farmers when they became interested in certain techniques (e.g., organic pest control) and asked their organic-farming neighbors and colleagues for advice. A similar multiplication effect was observed in many villages, leading to improved cooperation across the whole farming community. Nevertheless, a minority of organic and conventional farmers perceived deteriorating cooperation and sense of community, which they attributed to increasing individualism.

Potential and limitations for improving livelihoods

The results of our study suggest that organic farming is capable of improving the livelihoods of resource-poor small-scale farmers in the context of southern Kyrgyzstan. The economic benefits of fair trade organic cotton were widely acknowledged by organic farmers. However, these benefits did not simply stem from the higher value of organic cotton or higher farming grosses *per se*, but instead resulted from a combination of factors, foremost among them: (1) guaranteed sales of organic cotton for a higher, fixed price (organic plus fair trade premium) and partial pre-financing of the cotton harvest; (2) lower input costs and independence from agrochemicals; (3) access to timely credit on favorable terms; (4) support services from BioService and the BioFarmer Cooperative (extension and training, seed provision, marketing and lobbying); and (5) the provision of uncontaminated cotton oil and seed cake.

Organic farmers' livelihoods also appeared to benefit from a reduction of agronomic, environmental, health and economic risks. Crop rotation, a requirement of organic farming, results in more diversified production, which is associated with lower agronomic risks and higher food security compared to conventional farming—in contrast, one-third of the conventional farmers in the study sample produced cotton as a monoculture. Organic farming was also perceived to improve soil qualities and to greatly reduce health risks, as organic farmers were no longer exposed to toxic synthetic pesticides and did not consume contaminated cotton oil. Finally, the organic production methods combined with available support services seemed to reduce the overall economic risks faced by small-scale organic farmers in the study area.

Despite these positive results, certain limitations of organic farming should not be overlooked. Four key limitations were observed in the study area: First, the organic farmers perceived an increase in their workload. This appeared to affect women in particular, compounding the burden they were forced to bear due to male labor migration and the resulting labor shortages. Local stakeholders were asked whether they thought the 2009 global economic crisis would work to ease labor shortages in the study area. They suggested that local labor shortages would not be solved by the return of migrants who had lost their jobs in Russia because: (a) young people are generally uninterested in agricultural work, (b) those who lost their jobs abroad would likely stay there and look for new opportunities, and (c) those who did return would likely avoid agricultural work in favor of other business pursuits or off-farm activities. Thus, labor shortages likely remain a challenge in southern Kyrgyzstan's agricultural sector and may pose a constraint to widespread conversion to organic farming, even among farmers interested in making the transition. Secondly, in 2009, organic farmers still had very limited room for maneuver regarding adaptation to market trends and fluctuations, as cotton was the only crop fetching a higher price for organic production. Although the farmers did sell their rotation crops,—wheat, sunflower, etc.—none of them could be sold as organic, that is, at a higher premium price, because no local or regional market for organic crops existed and efforts to find an international buyer were hitherto unsuccessful. Thirdly, landholdings in the study area were small, and farmers of very small plots see little benefit in converting to organic farming. Fourthly, in some cases, insufficient supplies of manure presented a limitation to organic farming in the study area.

Conclusions

The period of conversion to organic farming is a critical time for small-scale farmers. During conversion, farmers' profits are typically reduced due to lower yields and because in-conversion cotton is ineligible for certified-organic premiums. Thus, to encourage organic farming, it appears necessary to offer interested farmers additional support to bridge the initial conversion phase; this was done in the study area by paying in-conversion farmers the fair trade minimum price plus a small premium. In southern Kyrgyzstan, organic farming would be much more attractive and profitable if rotation crops were also eligible for organic premiums. Past efforts to develop a local market or tap into international markets have been relatively unsuccessful—continuous work in this area is necessary.

The present study on Kyrgyz cotton production confirms the earlier conclusion of Nemes[16] based on analysis of over 50 case studies worldwide comparing the economic performance of organic and non-organic farming systems: organic price premiums appear crucial to the economic performance of organic farming; when combined with lower production costs, organic farms may become more profitable than conventional farms. The economic advantage of organic farming appears even greater if one considers the use of synthetic fertilizers and pesticides in conventional cotton production. Their use reportedly bears high risks for human and animal health as well as environmental damage, and may therefore lead to considerable

economic costs—for example, due to medical treatment, loss of animals or labor force. Frequently overlooked, these types of costs should also be considered when comparing the economic performance of production systems.

With its tiny market share—less than 1% of global cotton production—organic cotton currently represents a viable option and a lucrative niche for many small-scale farmers in developing countries, in particular due to attractive price premiums. However, these premiums may encourage more and larger producers to enter the market, which could in turn drive down the price premiums commanded by organic cotton[7]—a dynamic that has been previously observed in connection with established organic commodities such as rice, sugar and coffee[24]. Should this happen, organic cotton may lose some of its attractiveness to small-scale farmers.

In order to verify the positive impacts of organic cotton suggested above and the long-term viability of organic cotton farming in southern Kyrgyzstan, additional research is needed that includes measurements of important soil parameters as well as systematic, quantitative economic assessments of the costs and benefits of organic and conventional production systems. In light of the limitations of the present study regarding economic and soil data, the author recommends that organic initiatives strive to monitor the economic and ecological performance of organic and conventional farming more systematically. However, proper monitoring will require good baseline data, for example, yield levels and the status of soil fertility prior to conversion. In addition to collecting information on organic farms for an internal control system, it would also be useful to collect selected key information on conventional farming for the sake of comparative analysis and monitoring.

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An integrated mechanical and chemical method for managing prostrate cover crops on permanent beds

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Abstract

Cover crops in minimum or no-tilled systems are usually killed by applying one or more herbicides, thus significantly increasing costs. Applying herbicides at lower rates with mechanical interventions that do not disturb or bury cover crop residues can, however, reduce costs. Our objective was to develop a management system with the above-mentioned features for prostrate cover crops on permanent beds in an irrigated Vertisol. The implement developed consisted of a toolbar to which were attached spring-loaded pairs of parallel coulter discs, one set of nozzles between the individual coulter discs that directed a contact herbicide to the bed surfaces to kill the cover crop and a second set of nozzles located to direct the cheaper glyphosate to the furrow to kill weeds. The management system killed a prostrate cover crop with less trafficking, reduced the use of more toxic herbicides, carbon footprint, labor and risk to operators. Maximum depth of compaction was more but average increase was less than that with the boom sprayer control.

Key words: stubble, Vertisol, crop rotation, herbicide, toolbar, emissions

Introduction

Cover crops are frequently sown in rotation with high-value crops in many annual cropping systems. Several comprehensive reviews have been conducted on the subject during the past 15 years[1–4]. The cited advantages include better soil physical, chemical and biological quality (e.g., improved soil structure and water-holding capacity, higher soil organic carbon, increased numbers of beneficial micro-organisms and macrofauna, reduced numbers of disease-carrying micro-organisms and pests such as nematodes), improved nutrient recycling, weed control, soil hydrology (e.g., increased soil water storage and infiltration, reduced evaporation and runoff) and reduction in wind and water erosion[1–3,5–8]. In addition, leguminous cover crops can fix atmospheric nitrogen thus reducing costs of inputs[1,3,4] whereas cereals and grasses can take up excess residual nitrates, thereby reducing leaching and contamination of groundwater[3,4,7,9]. Disadvantages of cover crops include additional financial and environmental costs related to their sowing, management and control before sowing the main crop in the cropping system, potential weediness in subsequent crops and possible allelopathic, disease-enhancement and hosting of insect and other pests with respect to the main crop in the cropping system[1,4]. In cooler regions, cover crop mulch may reduce soil temperatures, thus affecting initial growth of the main crop[3]. Similarly, under conditions of reduced rainfall, the cover crop may have a negative effect on available soil water stocks[2].

In conventionally tilled systems the cover crop is usually mowed and incorporated before or during land preparation, and is commonly referred to as 'green manuring', whereas in minimum or no-tilled systems the cover crop is usually killed by applying one or more herbicides[4,10–12]. The latter contributes significantly to the costs of cover cropping in no-till systems[4]. In addition, the herbicides can be costly in terms of environmental quality. Consequently, several researchers have experimented with combining herbicides (at lower rates) with selected mechanical interventions that do not disturb or bury cover crop residues such as flail mowing, rolling, roller/crimper combinations, undercutting, etc.[10,13–19]. The literature suggests that most authors studied the use of mechanical methods, either alone or in combination with herbicides, with the objectives of rapid control of the cover, weed management and early planting.

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Figure 1. Killed vetch residues retained as *in situ* mulch in a bed-furrow system.

Some[14,15,18,19] also considered reducing herbicides due to environmental pollution or because cover cropping could be included in organic farming systems in which tillage could be excluded and the residues retained as surface mulch. The need to reduce amounts of herbicides such as *N*,*N*′-dimethyl-4,4′-bipyridinium dichloride (Paraquat) and 2,4-dichlorophenoxyacetic acid (2,4-D) due to their cost and toxicity (i.e., occupational health and safety reasons) was not a consideration in any of the studies reported in the literature. Among the above-cited research, most were conducted in flat-planted systems with only a very few addressing bed planting of cover crops[14,15].

Mechanical methods alone were variable with respect to cover crop control, with efficacy ranging from 10 to 100% and post-control emergence of weeds high in most instances. Teasdale and Rosecrance[10] and Kornecki et al.[18] reported that broadleaved covers such as hairy vetch [*Vicia villosa* Roth. (L.)] were not well controlled by mechanical methods alone, whereas Creamer et al.[15] and Creamer and Dabney[14] stated otherwise. Factors such as the height that the implement was set at, plot size, soil type and climatic variability may have contributed to this variation. Cereal cover crops such as rye (*Secale cereale* L.) could, however, be adequately controlled by mechanical means, particularly when control treatments were implemented post-anthesis[10,16–19]. Best control of a broadleaved prostrate cover crop and subsequent weed growth was when a contact herbicide (e.g., 2,4-D, Paraquat) was combined with mechanical methods, with treatments being implemented during early to mid-flowering[10,13], although Creamer et al.[15] and Creamer and Dabney[14] suggest that any time between early flowering and fruiting gave good control, even when mechanical means were the sole method of control. Herbicide such as glyphosate [*N*-(phosphonomethyl) glycine], a cheaper and safer option, could be used for covers such as rye[10,16–19]. No significant differences were reported when residual herbicides were combined with the contact herbicides.

The objective of this study was to develop an economically and environmentally acceptable management system which, relative to herbicide application with a boom-sprayer, minimized trafficking and reduced the use of the more toxic herbicides for killing a prostrate cover crop in furrow-irrigated permanent beds in a Vertisol. The cropping system tested was one in which vetch (*V. villosa* L. Roth, *Vicia benghalensis* L.), a prostrate leguminous cover crop, was followed by row-cropped cotton (*Gossypium hirsutum* L.). Our ultimate objective was to retain the vetch residues killed by the herbicides as *in situ* mulch into which the following cotton could be sown (Fig. 1). This report summarizes the development of an implement to manage vetch cover crops in a rotation experiment conducted from 2002 to 2010 in northern New South Wales (NSW), Australia.

The vetch cover crops have several issues and constraints that need to be addressed when their termination is under consideration:

- Vetch is a prostrate crop that forms adventitious roots through its lateral stems (also referred to as stolons or runners) and produces dry matter in the range of ~5–7 t ha^{-1} (Fig. 2). The bulk can be reduced by mowing with a slasher mower (Fig. 3). Depending on

Figure 2. Mowed (right) and unmowed (left) vetch crop.

Figure 3. Mowing vetch with a slasher-mower.

Figure 4. Applying Spray.Seed® in a single pass with an intermediate stage ('Later stage') of the mulching implement. (a) Complete implement under field conditions. (b) Close-up of strip cut by coulter discs. (c) Close-up of coulter-discs and nozzle.

climatic conditions, this kills about 20–50% of the vetch. The remainder can be killed either by incorporation or by application of a contact herbicide such as Spray.Seed® [11.5% (w/v) Paraquat and 9.8% (w/v) 6,7-dihydrodipyrido(1,2-a:2′,1′-c)pyrazinediium dibromide (1,1′-ethylene-2,2′-bipyridyldiylium dibromide). The formulation is more commonly stated as: Paraquat 135 g l^{-1} + Diquat 115 g l^{-1}). Mature vetch is tolerant of glyphosate.

- Spray.Seed® is highly toxic[20] and costlier than Roundup®. A 20 litre drum of Spray.Seed® is of the order of $A 215 (1 $A = 1 $US (January 2011)) and Roundup® (Glyphosate 450®, glyphosate 450 g l^{-1}) $A 80 (October 2010 prices).
- Survival of the prostrate vetch cover is enhanced through adventitious roots formed by the lateral stems. Personal observations by the authors suggest that adventitious root formation by the laterals is stimulated by mowing. Cutting the lateral stems can, however, minimize proliferation of adventitious roots.

The implement described in this report addresses the above constraints and issues in a single pass subsequent to mowing.

Figure 5. Applying Spray.Seed® to bed surfaces and Glyphosate 450® to furrows in a single pass with the final version of the mulching implement ('Final design').

Materials and Methods

Implement design

The design objectives of the implement were to kill and retain vetch residues as an *in situ* mulch while reducing the use of the more expensive and toxic herbicide Spray.Seed®. As noted previously, post-mowing survival of vetch could be reduced by mechanical methods that cut off the lateral stems, thus minimizing adventitious root proliferation. The initial design (Fig. 4a) consisted of a toolbar to which paired sets of parallel coulter discs were rigidly attached. The pairs of discs were located such that they ran on either side of the vetch plant line to a depth of ~2–4 cm, thus cutting off any lateral stems (Fig. 4b). It was assumed that the discs would follow the bed contours, thus ensuring a uniform cutting depth. A set of nozzles that directed herbicide (Spray.Seed®) to the vetch plant line on bed surfaces was located between individual disc pairs (Fig. 4c). The nozzles were attached to a tank that contained the herbicide. The discs also minimized herbicide drift. While this design was successful in reducing Spray.Seed® application amounts and killing the vetch, it also resulted in winter weeds such as wild Phalaris (*Phalaris paradoxa* L.), milk thistle (*Sonchus oleraceus* L.), dead nettle (*Lamium amplexicaule* L.) and wild turnip (*Brassica tournefortii* L., *Raphanus raphanistrum* L., *Rapistrum rugosum* L.) proliferating in the furrows, thus necessitating an additional application of a herbicide such as Glyphosate 450® with a boom sprayer.

The implement was subsequently modified to include a second tank and a second set of nozzles that directed an appropriate herbicide such as Glyphosate 450® to the furrows to control winter weeds. In addition, the rigidly attached coulters discs were replaced with spring-loaded coulter discs as the cutting depth of the former was variable. Thus, the final design consisted of a toolbar to which were attached four sets of spring-loaded pairs of parallel coulter discs, one set of nozzles that applied

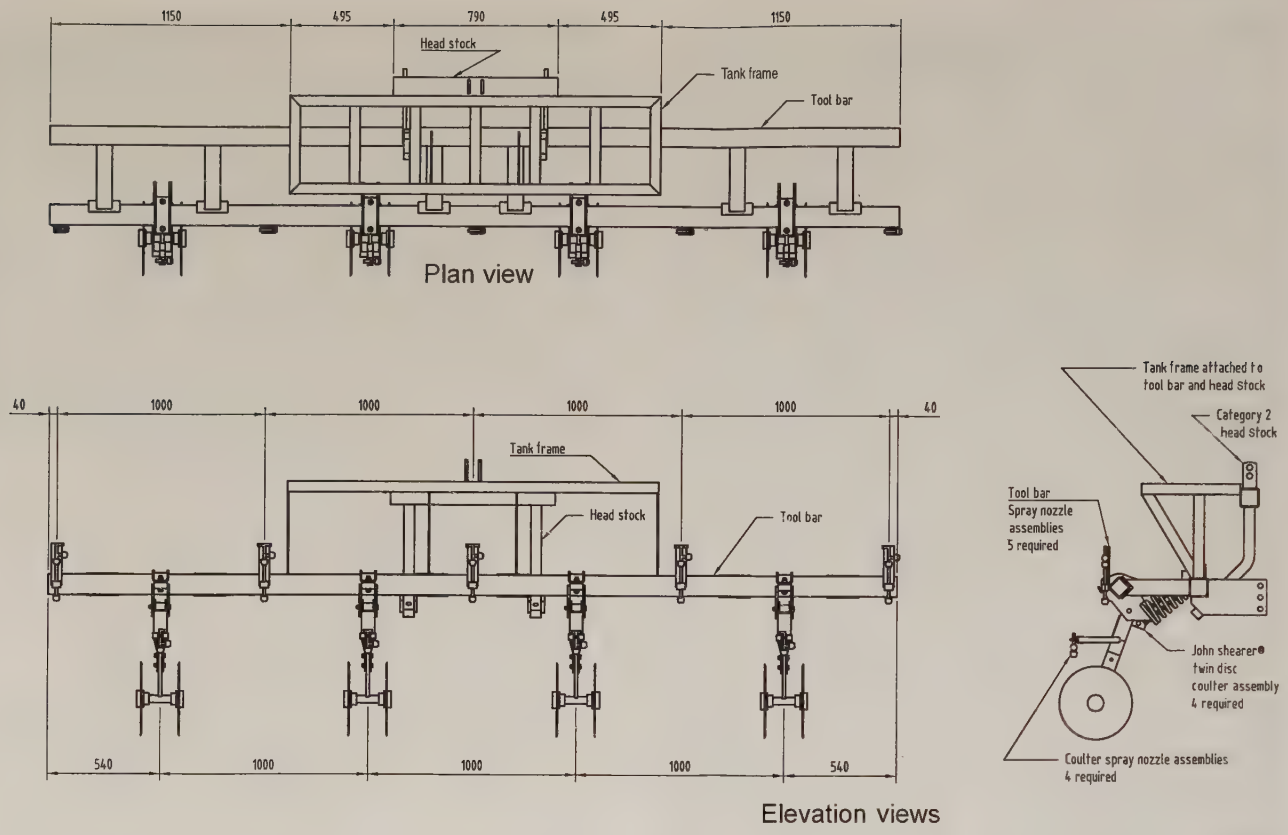

Figure 6. Line drawing of the final version of the mulching implement that was able to apply Spray.Seed® and Glyphosate 450® in a single pass. All component parts were purchased 'Off-the-shelf'. An image of the implement is shown in Figure 5.

herbicide (Spray.Seed®) to the bed surfaces located between individual discs and a second set of nozzles located to direct Glyphosate 450® to the furrow (Figs. 5 and 6). The two groups of nozzles were attached to separate tanks that contained the two different herbicides. Limiting Spray.Seed® application to a narrow band between two coulter discs ensures that herbicide drift is greatly reduced, thus minimizing non-target crop damage, and reducing exposure of farm workers to Spray.Seed®. Commercially available, 'off-the-shelf' components (nozzles, coulter discs, tanks, etc.) were used at all times.

Experimental

The mulching implement was developed during a cropping system experiment that commenced in 2002. The experiment was located at the Australian Cotton Research Institute, near Narrabri (149°47′E, 30°13′S) in NSW, Australia. Narrabri has a semi-arid climate and experiences four distinct seasons with a mild winter and a hot summer. The hottest month is January (mean daily maximum of 35°C and minimum of 19°C) and July the coldest (mean daily maximum of 18°C and minimum of 3°C). Mean annual rainfall is 593 mm. The soil at the experimental site is an alkaline, self-mulching, gray clay, classified as a fine, thermic, smectitic, Typic Haplustert[21] with a mean particle size distribution in the 0–1 m depth of 64 g/100 g clay, 11 g/100 g silt and 25 g/100 g sand.

The experimental treatments consisted of four irrigated cotton-based rotation systems sown on permanent beds: cotton monoculture, cotton–vetch, cotton–wheat (*Triticum aestivum* L.) where wheat stubble was incorporated into the beds after harvest with a disc-hiller, and cotton–wheat–vetch where wheat stubble was retained as an *in situ* mulch into which the following vetch crop was sown. Vetch in cotton–vetch and cotton–wheat–vetch rotations was killed before sowing cotton as described in the previous section and the residues retained as *in situ* mulch into which the following cotton was sown. Hairy vetch (*V. villosa* L. Roth) was sown from 2002 to 2004 and Popany vetch (*V. benghalensis* L.), which has an identical growth habit but is less hard seeded than hairy vetch, thereafter at sowing rates of 20 kg ha^{-1}. In NSW cotton is sown in October and picked in late April or early May after defoliation. Wheat and vetch in the cotton–vetch rotation were sown in May after cotton stubble was incorporated into the beds with a disc-hiller. Vetch in the cotton–wheat–vetch rotation was sown into wheat stubble after commencement of autumn rains, usually between late February and early April. Vetch was not fertilized and, depending on winter rainfall, received 1–2 irrigations of 100 mm each per season. Vetch was mowed with a 4-row slasher at 50% flowering. Vetch dry matter production at time of mowing was estimated by

Table 1. Estimated emissions and labor requirements (including setting-up time). JD, John Deere; weight of the JD 8100 was 8.8 t, JD 6200 3.8 t, 8-row boom sprayer with 550 l of herbicide 1.0 t and 4-row coulter/band sprayers in Stages 2 and 3, 0.6 and 0.7 t, respectively. Emissions estimated for herbicide and fuel production include those associated with transport.

Options	Operation	Tractor	Implement	Diesel used ($l\,ha^{-1}$)	In-field emissions	Herbicide production emissions	Fuel production emissions	Total	Labor ($man\,h\,ha^{-1}$)
					CO_2-e ($kg\,ha^{-1}$)				
Stage 1 (no implement)	Mowing	JD 8100	4-row slasher	10.7	31.0		4.5	35.5	3.5
	Applying Spray.Seed® ($3\,l\,ha^{-1}$) × 2	JD 6200	8-row boom sprayer	4.4	12.8	20.0	1.9	34.7	5.0
	Applying Glyphosate 450® ($3\,l\,ha^{-1}$)	JD 6200	8-row boom sprayer	2.2	6.4	28.8	0.9	36.1	2.5
Total				17.3	50.1	48.8	7.4	106.3	11.0
Stage 2 (later stage)	Mowing	JD 8100	4-row slasher	10.7	31.0		4.5	35.5	3.5
	Applying Spray.Seed® ($3\,l\,ha^{-1}$)	JD 6200	4-row coulter/band sprayer	6.2	17.8	10.0	2.6	30.4	3.5
	Applying Glyphosate 450® ($3\,l\,ha^{-1}$)	JD 6200	8-row boom sprayer	2.2	6.4	28.8	0.9	36.1	2.5
Total				19.1	55.1	38.8	8.1	102.0	9.5
Stage 3 (final design)	Mowing	JD 8100	4-row slasher	10.7	31.0		4.5	35.5	3.5
	Applying Spray.Seed® ($3\,l/\,ha^{-1}$) + Glyphosate 450® ($3\,l\,ha^{-1}$)	JD 6200	4-row coulter/band sprayer	6.2	17.8	38.8	2.6	59.2	3.5
Total				16.9	48.8	38.8	7.2	94.7	7.0

harvesting $3 \times 1\,m^2$ sub-plots in each plot and means compared with Student's *t*-test. After mowing, the previously described implement was employed to kill vetch re-growth.

The experiment was laid out as a randomized complete block with three replications and designed such that both cotton and rotation crop phases in the last two rotation treatments were sown every year. Individual plots were 165 m long and 20 rows wide. The rows (beds) were spaced at 1 m intervals with vehicular traffic being restricted to every second furrow. Details of soil and crop management practiced in this experiment have been reported by Hulugalle et al.[22].

Detailed records were maintained of labor requirements associated with both setting up and in-field operation of the implement in its early and final versions. Detailed records were also kept of fuel use, herbicide application rates and costs. Fuel use and greenhouse gas emissions [as carbon dioxide equivalents (CO_2-e)] associated with vetch control, herbicide and fuel production and transport were estimated from available sources[23–26]. The above information was used to assess labor requirements, and greenhouse gas emissions associated with herbicide and fuel production for three developmental stages of the vetch management system (Table 1). Briefly, these were:

- Stage 1: Mowing followed by applying Spray.Seed® with two passes of an 8-row boom sprayer ('No implement'). Occasionally, an additional application of Glyphosate 450® with a single pass of a boom sprayer was required.
- Stage 2: Mowing followed by applying Spray.Seed® in a single pass with an intermediate stage of the implement (Fig. 4a) and Glyphosate 450® with a single pass of an 8-row boom sprayer ('Later stage').
- Stage 3: Mowing followed by applying Spray.Seed® and Glyphosate 450® with the final version of the implement in a single pass (Fig. 5) ('Final design').

During October 1, 2010, the effects of trafficking associated with the three developmental phases of the implement (no implement, later stage, final design, see Table 1 for details) on penetrometer resistance, which is related to soil compaction[27], was evaluated in wheel-tracked furrows of plots sown with the cotton–vetch rotation. Due to obsolescence, the JD 6200 tractor (3.8 t) used to pull the implement and the boom sprayer was replaced in 2010 with a JD 6130 (6.0 t) for the 8-row boom sprayer operations (Stages 1 and 2) and a JD 5303 (3.8 t) for the 4-row implement used in Stages 2 and 3. Penetrometer resistance to a depth of 0.45 m was measured before and after trafficking at 15 mm depth increments in six sites (three insertions per site) selected at random in each plot in wheel-tracked furrows with a Rimik® CP10 recording cone penetrometer fitted with a standard 30° circular stainless-steel cone of 12.83 mm diameter and a 9.83 mm-diameter shaft. Gravimetric water content was measured at 0.10 m depth intervals in soil sampled at the same time from the same locations with a tractor-mounted soil corer. Penetrometer

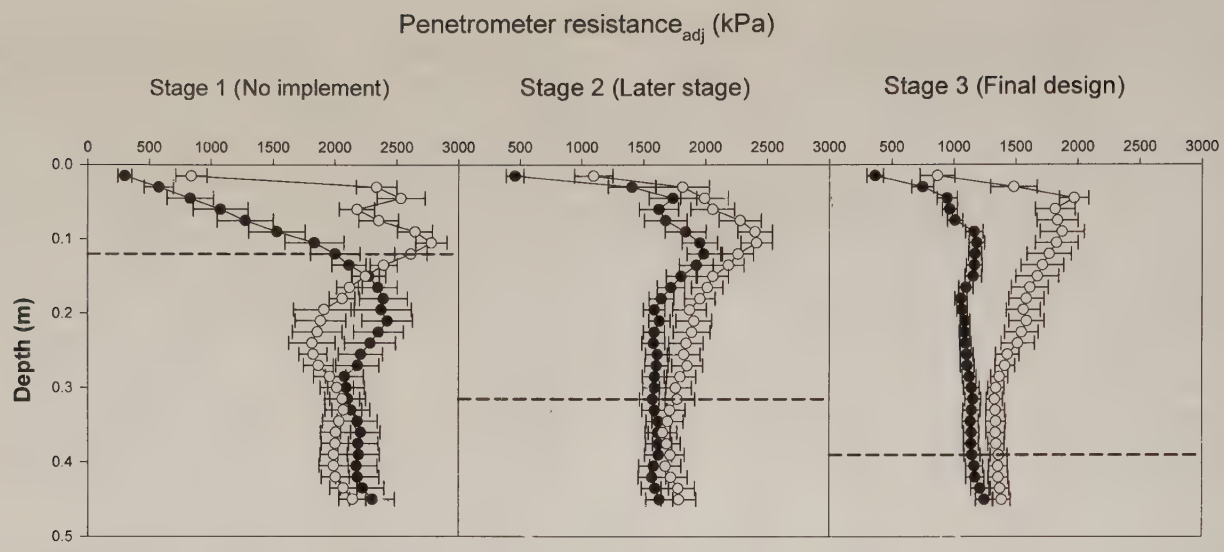

Figure 7. Penetrometer resistance (standardized to a gravimetric soil water content of 0.275 g g^{-1}) to a depth of 0.45 m with the three developmental stages (Table 1) of vetch management, October 5, 2010. ●, Before trafficking; ○, after trafficking. Stage 1: Mowing followed by applying Spray.Seed® with two passes of an 8-row boom sprayer ('No implement'); Stage 2: Mowing followed by applying Spray.Seed® in a single pass with an intermediate stage of the implement and Glyphosate 450® with a single pass of an 8-row boom sprayer ('Later stage'); Stage 3: Mowing followed by applying Spray.Seed® and Glyphosate 450® with the final version of the implement in a single pass ('Final design'). Horizontal bars are standard errors of the means. The dotted line represents the maximum depth at which significant changes were detected.

readings were adjusted to a standard water content of 0.275 g g^{-1} (~field capacity)[28] and pre- and post-trafficking values were compared by means of a Student's *t*-test. Standard errors of individual means were computed.

Results and Discussion

Vetch dry matter production

Dry matter (mean ± standard deviation) produced by vetch at the time of harvest was 3.4 ± 1.2 t ha^{-1} in the cotton–vetch rotation and 5.0 ± 1.7 t ha^{-1} in the cotton–wheat–vetch. The higher ($t = 7.28$, df = 53, $P < 0.001$) yield in the latter rotation was probably due to a longer growing season (5–6 months) relative to the vetch in the cotton–vetch rotation (~4 months).

Greenhouse gas emissions, and herbicide and labor costs

In-field fuel use and greenhouse gas emissions, and emissions associated with fuel production and transport were in the order of Stage 2>Stage 1>Stage 3 (Table 1). This was because, relative to Stage 1, 10% more fuel was used by Stage 2 and 3% less by Stage 3. Emissions associated with herbicide production and transport were, however, in the order of Stage 1>Stage 2 = Stage 3. In comparison with Stage 1, herbicide production and transport resulted in Stages 2 and 3 emitting 21% less CO_2-e. This was because Stages 2 and 3 used less herbicides. Overall, emissions associated with in-field activities, and herbicide and fuel production and transport were least in Stage 3: 11% less than Stage 1 and 7% less than Stage 2.

A significant proportion of emissions (32–37%) in all three stages were accounted for by the mowing. It is likely that major improvements in terms of fuel and emission reduction may be achieved by seeking alternatives to the slasher. Kornecki et al.[16,17] have suggested using various forms and combinations of roller crimpers. Flail mowers, undercutters, cutter bars and band mowers are other possible alternatives[14,15,29,30]. An alternative to mowing may be to graze the vetch with livestock, although this may result in N fixed by the vetch moving off-field when the stock are relocated. The subsequent crop may, therefore, not benefit from the N fixation by the vetch.

Costs of herbicides (using September 2010 prices of $A 10.75 litre^{-1} of Spray.Seed® and $A 4 litre^{-1} of Glyphosate 450®) were of the order of $A 75.50 ha^{-1} for Stage 1, and $A 44.25 ha^{-1} for Stages 2 and 3. In all three stages, a complete kill of vetch and weeds was obtained. In Stage 3 ('Final design'), Spray.Seed® was applied at an overall average rate of 3 l ha^{-1} to a 0.2 m wide band at 1 m intervals (i.e., 20% of the land area). Glyphosate 450® was similarly applied to 80% of the area.

Labor requirements were of the order of Stage 1> Stage 2> Stage 3 (Table 1). Stage 3 required 36% less labor than Stage 1, and 26% less labor than Stage 2. This is a significant cost saving. For example, assuming that the hourly cost to an employer for a farm worker is $A 31.55 h^{-1} [salary of $A 45,000/annum and on-costs (sum of payroll tax, workers compensation, leave loading,

extended leave and superannuation) of 35%], then estimated labor costs ha^{-1} would be of the order of $A 347 for Stage 1, $A 300 for Stage 2 and $A 221 for Stage 3. Other benefits would include reduced herbicide exposure and fatigue to workers due to reduced working hours and Spray.Seed® application rates.

Penetrometer resistance

Depth and pattern of compaction in furrows, as indicated by changes in penetrometer resistance, differed among the three stages (Fig. 7). Maximum statistically significant depth of compaction was shallow in Stage 1 and was of the order 0.120 m with an average (geometrical mean) increase of 101% in the 0–0.120 m depth, whereas maximum depths of compaction in Stages 2 and 3 were 0.315 and 0.390 m, respectively, and average increases to maximum depths of compaction were 20 and 39%, respectively. In other words, Stage 1 (total weight of 6.9 t, axel load of 1.0 t) had a shallow but intense pattern of compaction, whereas Stages 2 and 3 had less intense but deep compaction patterns. In comparison with Stage 2, more intense and deeper compaction occurred with Stage 3. Although there was a weight differential between Stage 3 (total weight of 4.5 t, axel load of 0.7 t) and Stage 2 (total weight of 4.4 t, axel load of 0.6 t), the small difference of 0.1 t alone does not adequately explain the near doubling of compaction between the two stages. We surmise that relative to Stage 2 (Fig. 4a), the inclusion of an additional tank and altered weight distribution in Stage 3 (Fig. 5) may have resulted in a significant increase in vibrations, and when combined with the relatively moist, clayey soil, a deeper and more intense compaction (and possibly, smearing) may have occurred in the latter[31]. The varying patterns of compaction between Stage 1, and Stages 2 and 3 may be due to a combination of factors such as greater weight of the tractor/boom sprayer/herbicide tank combination (6.9 t), more vehicle passes and wider tyres in the JD 6130 used in Stage 1 (Table 1) relative to the JD 5303 used in Stages 2 and 3[31]. Widths of the front and back tyres of the JD 6130 were 410 and 320 mm, respectively, and of the JD 5303 were 370 and 240 mm, respectively. Air pressure in the tyres is unlikely to have been a contributory factor as those in the JD 6130 were higher (207 and 117 kPa in the front and back tyres, respectively) than those in the JD 5303 (124 and 103 kPa in the front and back tyres, respectively). Soane et al.[31] note that shallow compaction patterns are characteristic of wider tyres and low air pressure.

Conclusions

An integrated mechanical and chemical management system that was able to kill aggressive and bulky prostrate cover crops such as vetch with fewer machine passes, also reduced use of more toxic herbicides such as Spray.Seed®, decreased labor, lowered risk to operators and had a lower carbon footprint. In comparison with spraying with an 8-row boom sprayer, the depth of compaction was more when this 4-row implement was used, although the former resulted in more intense and shallower compaction.

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Indian farmers' experience with and perceptions of organic farming

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Abstract

In India, the number of farmers converting to organic farming has increased in the recent past despite the lack of government support in providing knowledge and extension to the farmers. The aim of this article is to investigate the perceived relevance, benefits and barriers to a conversion to organic agriculture in three different Indian contexts—in Tamil Nadu, Madhya Pradesh and Uttarakhand states. In each state, 40 farmers from both organic and conventional systems were interviewed. The findings indicated that conventional producers identified production and marketing barriers as the main constraints to adopting organic farming, while the age and education of the farmer were not deemed a problem. Lack of knowledge and lack of institutional support were other barriers to conversion. Some farmers were, however, interested in converting to organic farming in the near future in Madhya Pradesh due to the low cost of production, and in Tamil Nadu and Uttarakhand due to the price premium and health benefits. On the other hand, organic farmers were more concerned with health, environmental and production factors when institutional support was available. The years under conversion were positively associated with reduced input costs in all three states and with increased income in Tamil Nadu and increased yield in Madhya Pradesh. Both organic and conventional farmers found the two production factors, low yield and pest control, to be of major concern. However, organic farms in Madhya Pradesh and Uttarakhand experienced yield increases because most of the farms were in the post-conversion period, while the farms in Tamil Nadu were in the conversion period and experienced yield reduction. The study suggests that the government scheme for compensating yield loss during the conversion period and a price premium may help farmers adopt organic agriculture on a large scale in India.

Key words: organic farming, farmers' perceptions, organic farmers' experience, India

Introduction

Technologies that powered the Green Revolution such as the use of high-yielding varieties, chemical fertilizers and pesticides, coupled with the expansion of the area under irrigation transformed India from a net food importer in the 1950s and 1960s to a self-sufficient nation in the 1980s[1]. However, the techniques that were used to increase agricultural yield have led to significant surface and ground water contamination, an increased incidence of pests and diseases, and loss of biodiversity[2–6]. Increased production costs and indebtedness are other problems faced by farmers in India[2,7–9]. All these problems have created an interest in organic agriculture among farmers, researchers, policy-makers and other stakeholders.

Organic agriculture is an integrated production system based on active agro-ecosystem management rather than external inputs[10]. Organic agriculture includes both certified and non-certified food systems. Farming systems that actively follow organic principles are considered organic, even if the agro-ecosystem or the farm is not formally certified as organic[11]. Studies from across the world have shown that both economic factors, such as increased income, reduction in the input cost and the opportunity to get a premium price for the harvest[12–16], and non-economic factors, such as improved soil fertility, environmental protection, quality food products and health[17,18], influenced the farmer's decision to adopt organic farming.

With a total of 1.02 million ha in organic production, India has the largest number of organic farms (340,000) in

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Figure 1. Location of the surveyed states in India.

the world, registering a growth increase of 87% in the export of organic products over the past 3 years[19]. Different factors have persuaded farmers to convert. In Kerala,[20] homestead farmers growing coconut were persuaded by socio-psychological factors such as education, risk orientation and knowledge, while the negative impact of conventional agriculture on environment and revenue influenced the farmers in Karnataka[21]. However, low yield, lack of organic manures and lack of technical knowledge were the major constraints for adopting organic farming in Maharashtra[22].

The above few studies focused on specific crops, except for a study about organic cotton farming and its impact on the livelihood of small and medium-sized farmers in Madhya Pradesh[23]. However, little research has been carried out at farm scale for resource-poor, organic, small farmers, taking into account the way in which activities of non-governmental organizations (NGOs) may impact on perception and possibilities to convert from conventional to organic farming. Therefore, the present study was undertaken in three states of India, namely Madhya Pradesh, Tamil Nadu and Uttarakhand, with the following research questions:

1. What are the barriers for conversion to organic farming?
2. What are the motives for conversion to organic farming?
3. What are the advantages and challenges in practicing organic farming?

Understanding these would help researchers, policy-makers and other stakeholders to develop strategies to increase the adoption of organic farming in India, where it is expected particularly to benefit smallholder farmers.

Methods

The research was designed to cover three states of India in order to represent three very different situations in terms of agro-ecological conditions, farming system, market access and activities of NGOs promoting organic farming. The states chosen were Madhya Pradesh, Tamil Nadu and Uttarakhand (Fig. 1).

Context of organic farming in the case areas

The function of the NGOs in the three states is described below.

BioRe India in Madhya Pradesh. BioRe India is a private agribusiness company, promoting organic cotton production in Madhya Pradesh and export to Europe. The company started as a non-commercial experiment to help cotton farmers reduce their debt and secure a sustainable livelihood and became an enterprise with the social responsibility to combine ecology with economic profit[24]. At present, the BioRe India project is active in the Nimar Valley, involving 6400 smallholders who cultivate 6502 ha of cotton and produce more than 3963 tonnes of seed cotton per year.

An independent but related organization, the BioRe Association, runs a training center offering education in organic farming and provides interest-free credit to farmers to develop infrastructure such as biogas facilities, vermicomposts, irrigation facilities and provisions for safe drinking water. BioRe Association also provides farmers with farm inputs such as seeds, de-oiled castor, rock phosphate, botanical and microbial pesticides, etc., if needed. The company also provides vocational training and advisory services. BioRe enters into 5-year purchase guarantee contracts with farmers, purchases the seed cotton at prevailing market rates and pays an up to 20% price premium at the end of the season to the farmers who have completed the 3-year conversion period. In the first year, farmers receive the inputs on a credit basis, while in the following years input costs are adjusted with the price premium from the previous year.

Center for Indian Knowledge System (CIKS) in Tamil Nadu. CIKS is an NGO active in Kancheepurm, Thiruvannamalai, Dindugal and Nagapattinam districts of Tamil Nadu and farmers were all still in the conversion period during the time of study. The NGO provides short-term training programs and follow-up training sessions for practicing organic farming. The farmers were trained on various aspects of organic farming such as soil conservation, enriching soil fertility, pest and disease identification and their organic management techniques, kitchen gardening, compost and vermicompost production, bio-pesticide preparation, etc. Monthly meetings were arranged for each organic farmers' group at the behest of the NGO to discuss organic farming and the farmers' experience in practicing it. During the initial stages of the conversion period, inputs such as traditional variety seeds, biofertilizers, green manure seeds, neem cake, etc., were supplied by the organization through the project. Demonstration fields were set up in all four districts, these fields served as learning centers for the farmers and helped to create awareness about organic farming among the farmers of neighboring villages also.

An organic farm production society was established in each of the four districts. Currently, most of the marketing activities are taken care of by these societies by direct contact with consumers living near cities. The societies sell the products to consumers with a 10% price premium. Under certain circumstances CIKS also buys organic products on its own from the farmers with a 10% premium and sells them directly in markets located as far away as Chennai, the state capital.

Navdanya in Uttarakhand. Navdanya is active in 16 states of India, although it mainly focuses on Uttarakhand. It has trained 200,000 farmers in organic production. Navdanya provides short-term training programs and follow-up training sessions for farmers interested in organic farming and for farmers interested in being self-reliant in the input use of locally available resourses. It also arranges exposure visits to other organic farms. Navdanya has its own community seed bank, conserved indigenous varieties and organic farm spread over a 20-acre area of in Uttarakhand, north India. This farm is used as a demonstration farm for the farmers. Navdanya buys organic products from farmers with a 10% price premium. Most of the organic farmers are linked to the local market. In some instances there is a direct marketing link between Navdanya's consumer members and producer members, and in a few cases a door-to-door organic vegetable basket delivery is operated.

Agroecological conditions

Madhya Pradesh lies in the central part of India. Three districts of Madhya Pradesh—Barwani, Khargaon and Khandwa—were identified for data collection. These are classified under the agroecological region/subregion-5.2/ I5Dm4 as hot semi-arid ecosystems with deep black soils, and average annual rainfall is 800–1000 mm with a mean temperature of 24–25°C[25]. Cotton is the main crop which, on a national scale, covers only 5% of the total cropped area, but consumes 28% of the total pesticide usage in India[26]. Most of the cotton was intercropped with soybean, pigeon pea and urad bean. Conventional farmers used fertilizers and manures for soil nutrient management and pesticides for managing pests and diseases. Organic farmers used organic inputs such as DOC (castor de-oiled cake), farmyard manure, compost and neem cake, and biodynamic inputs such as BD500 (cow horn manure) and CPP (cow pat pit manure) for soil fertility management[27], and they used bio-pesticides such as beevicides (*Beauveria bassiana*), veralac (*Verticillium lecani*) and neemzalthe extract from neem seed kernel for managing pests and diseases in cotton and other crops.

Tamil Nadu is the southernmost state of India. Four districts—Kanchipuram, Tiruvannamalai, Nagappattinam and Dindugal—were identified for data collection. These are classified under the agroecological region/subregion-8.3/ H1Dm4 eastern ghat as a hot semi-arid ecosystem with red loamy soils[25]. Rice is the major crop, which is mostly sown in July–August and harvested in November–January, whereas pulses and peanut typically are grown from

January to April. Conventional farmers of the state, who took part in the study, used fertilizers and manures for soil nutrient management and used pesticides for managing pests and diseases. Organic farmers, on the other hand, used farmyard manure, vermicompost, bio-fertilizers, green manure and neem cake for soil fertility management, and bio-pesticides such as neem oil, amirtha karaisal, five-leaf extract, pheromone traps and panchakaviyam for controlling pests and diseases.

Uttarakhand lies in the northern part of India. Four districts—Dehradun, Tehri Garwal, Uttarkashi and Rudraprayag—were chosen for the data collection. Uttarakhand is classified under the agroecological region/subregion-14.4/A3 (B/A) 9 Kumaun Himalayas as a warm perhumid to perhumid ecosystem with red and yellow soils[25]. The major crops grown in this state are rice, maize, millet and pulses from June to October, and wheat, oats, mustard and potatoes from November to April. Most of the farms included in the study grew diverse crops using locally available resources and preserved some of the harvest for seed purposes. Conventional farmers used synthetic chemicals in the form of fertilizers and pesticides for soil nutrient and pest management. Organic farmers used compost, farmyard manure, green manure and crop rotation for soil nutrient management, and natural pesticides along with physical traps, crop rotation, etc., for managing pests and diseases.

Data collection and analysis

BioRe India involves 6400 smallholders in Madhya Pradesh, CIKS is active in four districts involving 1600 smallholders and Navdanya is working in Uttarakhand with several thousands of farmers for organic production. From these populations, 20 villages (five villages from each of the four districts in Tamil Nadu and Uttarakhand; seven villages from each of two districts and six villages from one district in Madhya Pradesh) were randomly selected from each state. In each of those villages, two organic farmers were randomly selected from lists of organic farmers supplied by the NGOs. Matching conventional farms similar in basic characteristics were identified from the list provided by the local advisor. Thus, two organic and two conventional farmers from each village, totaling 40 organic and 40 conventional farmers, were interviewed in each of the three states. Pre-testing of the questionnaire was done in December 2007 and data were collected in spring 2008. Three people in total, one from each state, were trained in using the questionnaire by the first author by interviewing a few farmers in each state. The questionnaire was prepared in a Hindi version for data collection in Madhya Pradesh and Uttarakhand, whereas the original version of the questionnaire in English was used for Tamil Nadu. Data were collected by these three trained people. Data were further screened to avoid inadvertent inclusion of incomplete data or data from large farms in the study. After preliminary screening, the data were used for further statistical analysis.

The questionnaire for organic farmers included questions on: (1) demographic aspects of farmers, such as age, family size, education and main occupation; (2) motives for conversion to organic farming; (3) farmer's experience of the advantages and challenges of practicing organic farming; (4) farmer's experience related to changes in cropping pattern, biodiversity, market access and credit issues. The questions for conventional farmers included: (1) demographic aspects, such as farmer's age, family size, education and main occupation; (2) barriers for conventional farmers for conversion to organic farming; (3) perceptions about organic farming in relation to production and market issues.

To understand the farmers in the best way possible, the questions on motives for conversion to organic were open ended, which provided more scope for the farmers to construct answers to explain their own motives at the time of conversion. Most of the farmers mentioned one or two motivating factors describing their own expectations from organic farming. Similarly, the question on barriers was open ended to enable the farmers to describe their perceptions in their own words instead of limiting them to those conceived by the project team.

A ranking procedure was used to measure farmers' experience with the advantages and challenges of organic farming by a prepared set of possible replies. Organic farmers were asked to rank four out of eight possible advantages of organic farming, such as improved soil fertility, environmental benefits, avoidance of chemicals, increased health benefits, reduction of input cost, higher price, higher yield and assured market for the organic products. Likewise, organic farmers were asked to rank four out of six possible challenges, such as insufficient manure, difficulties in pest and disease control, weed control, unavailability of labor, low yield and problems with market price they had encountered. To determine the top four advantages in each state, we used a scale-ranking method. A four-point scale was attached to each of the possible responses, with 4, 3, 2 and 1 points assigned to the responses chosen by the farmer as first, second, third and fourth advantage, respectively. The same method was applied to find the top four challenges in each state. The points were then totaled under each item and divided by N ($N = 39$ for Madhya Pradesh, 40 for Tamil Nadu and Uttarakhand) to obtain mean values of individual items.

The farmers who practiced organic agriculture were given the choice of answering 'yes/no/do not know' on the questions on whether they had experienced changes in the cropping pattern, improved access to market and credit, and increased biodiversity in organic systems. Similarly, conventional farmers were asked to choose 'yes/no/do not knows' to the questions related to organic farming to know their perceptions about it.

Data were analyzed using SPSS (SPSS Inc., Chicago, Illinois, USA). Differences with P-values less than 0.05 were considered statistically significant. Chi-square tests

Table 1. Demographic characteristics of conventional and organic farmers in three states of India.

State		Madhya Pradesh			Tamil Nadu			Uttarakhand		
	System	Con[1]	Org[2]	*P* value	Con	Org	*P* value	Con	Org	*P* value
1	Family size (number)	5	4.6	NS	4.2	4.28	NS	4.6	5.2	NS
2	Age of household head (years)	41	42	NS	45	44	NS	46	43	NS
3	Occupation of household head									
	(a) Farming as main occupation (%)	92	87	NS	92	92	NS	100	100	NS
	(b) Farming as secondary occupation (%)	8	13		8	8		0	0	
4	Education of household head									
	(a) No education (%)	23	46	***	0	3	NS	23	10	***
	(b) 5 years of schooling (%)	45	26		32	21		46	43	
	(c) 6–12 years of schooling (%)	12	13		57	63		23	41	
	(d) University education (%)	20	15		11	13		8	6	
5	Cultivated area (ha)	1.2	1.5	*	1.0	1.0	NS	0.4	0.56	NS
6	Experience of organic farming (years)		4(2–8)			2.7(1–6)			6.3(3–10)	

[1] Conventional farming system.
[2] Organic farming systems.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. NS, not significant.

were used to test for difference in distribution patterns in conventional farmers' perceptions in all the three states studied. Similar tests were performed on organic farmers' experience. The relationship between answers on the different issues and farmer age, education and experience was tested using AMOS™17.0 (Analysis of Moment Structures).

Results

Demographic characteristics

The general demographic characteristics in each case area are presented in Table 1. Demographic characteristics were similar for organic and conventional farms in all three case areas, although education of household head differed significantly in Madhya Pradesh and Uttarakhand. In Madhya Pradesh, a larger proportion of organic farmers had no education compared to conventional ones, whereas in Uttarakhand organic farmers had on average a higher education—fewer had no education and a higher proportion had 6–12 years of schooling. Average family size was found to be 4–5 and the average age of farmers ranged from 41 to 45 in all surveyed case areas. Farming was the main occupation for all organic and conventional farmers.

All the surveyed farms were small, cultivating less than 2 ha. The cultivated area was similar for organic and conventional farms in Tamil Nadu and Uttarakhand, while a significant difference was found in Madhya Pradesh, where organic producers had a larger area than conventional producers (Table 1). In Madhya Pradesh, they had practiced organic farming for 4 years (2–8 years) and most of the farms were certified except for a few farms in conversion. In Tamil Nadu, organic farming had been practiced for 2.7 years (1–6 years), and all the farms were non-certified. The farmers in Uttarakhand had farmed organically for 6.3 years (3–10 years) and 85% of the farms were non-certified.

Barriers to conversion for conventional farmers

The responses of conventional farmers to the open-ended questions regarding the barriers are listed in Table 2. The response was low on this question, with only 68, 85 and 53% of surveyed farmers responding in Madhya Pradesh, Tamil Nadu and Uttarakhand, respectively. The chi-square test showed that there were significant differences in the barriers identified by the conventional farmers across the states, although low yield was first on the list in all three case areas. In Madhya Pradesh and Tamil Nadu, the control of pests and diseases was also regarded as a problem. Lack of technical knowledge, fragmented land (difficult for group certification) and lack of organic inputs were the other barriers as perceived by conventional farmers in Madhya Pradesh. Interestingly, one farmer from Madhya Pradesh identified as a barrier the fact that Bt cotton is not allowed in organic farming, and five farmers from Tamil Nadu felt that organic farming was not suitable for their style of farming. Other barriers were lack of organic inputs, labor requirements, tenancy and lack of a market among Tamil Nadu farmers.

Conventional farmers' perception of organic farming

The response to open-ended questions on barriers was low in all three states, maybe due to difficulties in framing the answer. Hence, farmers were asked to answer 'yes/no/do not know' on production issues, market access and health benefits in organic farming (Table 3). The chi-square test showed that the distribution pattern of answers differed in all three states for all the issues, except for low input cost

Table 2. Barriers for conversion to organic farming as described by conventional farmers.

	Number of respondents mentioning each factor		
	Madhya Pradesh	**Tamil Nadu**	**Uttarakhand**
Number of farmers interviewed	40	39	30
Number of farmers responded	27	33	16
Barriers mentioned by farmers			
1. Low yield	15	22	16
2. Problem in controlling pest and disease	5	5	0
3. Non-availability of organic inputs	2	3	0
4. No knowledge	5	0	0
5. No market	1	1	0
6. Not suitable for me	1	5	0
7. Lack of labor	1	2	0
8. Difficulty in livestock management in OF	0	1	0
9. Rain-fed lands	1	2	0
10. Fragmented land	4	0	0
11. Bt cotton not allowed in organic farming	1	0	0
12. Rented land	0	2	0

Note: Nine farmers in Madhya Pradesh and 10 farmers in Tamil Nadu mentioned two barriers.
Chi-square test showed a significant difference ($P < 0.001$) across the states mentioning barriers.

which had a similar pattern. In Madhya Pradesh and Tamil Nadu, there was less opportunity to convert to organic farming than in Uttarakhand, since BioRe in Madhya Pradesh selects the farmers they deem suitable for the certification process, and in Tamil Nadu, the NGOs also had to restrict the number of farmers in taking part in the organic farming project. Hence, the option of organic is not available to all the farmers despite it being a non-certified organic system. In contrast, all the farmers in Uttarakhand had the option to join, and Navdanya provided technical expertise for interested farmers, but not much support in terms of credit and organic inputs, unlike other NGOs in Tamil Nadu. In terms of farmers wishing to convert to organic farming in the near future, the figures for Madhya Pradesh, Tamil Nadu and Uttarakhand were 25, 20 and 93%, respectively.

The majority of the conventional farmers perceived organic farming having reduced input costs in all three case areas (Table 3). However, yield and labor issues were differently weighted in the case areas. Conventional farmers in Madhya Pradesh and Tamil Nadu were most concerned about low yield, while Uttarakhand farmers were least concerned. Likewise, Tamil Nadu farmers were concerned with labor issues, while Uttarakhand farmers were not and Madhya Pradesh farmers were unsure of labor issues.

Most of the conventional farmers in Madhya Pradesh were not sure of a price premium and market assurance for the organic products, whereas their counterparts in Tamil Nadu feared the lack of a market and premium price for the organic products (Table 3). Uttarakhand farmers, on the other hand, had positive thoughts about the price but were not sure of the market. Tamil Nadu and Uttarakhand farmers had a positive attitude toward product quality and health, while Madhya Pradesh farmers were unaware of that.

We investigated whether the answers on production, market and health issues were influenced by the farmer's age and education using AMOS. The results showed that farmer's age and education did not influence the answer in all three case areas. AMOS was also used to investigate which factors influenced some farmers' willingness or interest to convert in the near future. The results showed that low input cost was the main determinant in Madhya Pradesh, while a price premium along with health benefits were the main determinants in Tamil Nadu. The production, price premium and health factors influenced 93% of the farmers in Uttarakhand.

Organic farmers' reasons for converting to organic farming

The reasons given by the organic farmers for converting to organic farming are listed in Table 4. All the interviewed farmers in Tamil Nadu responded, while four farmers in Madhya Pradesh and 12 farmers in Uttarakhand refused. This still resulted in a response rate that was higher than for conventional farmers. In Madhya Pradesh, 35, 34, 19 and 4 farmers listed one, two, three and four reasons, respectively, whereas 40, 36, 11 and 3 farmers listed one, two, three and four reasons, respectively, in Tamil Nadu. In Uttarakhand, 28, 15 and 2 farmers listed one, two and three reasons, respectively.

The chi-square test showed that there were significant differences in the reasons across states, although a few of the factors (soil fertility improvement; low input cost and health) were common at the top of the list. The major difference was that the wish to avoid chemicals was mentioned only in Tamil Nadu. The reasons for local availability of organic inputs, diversified production and higher yield were mentioned only in Uttarakhand, and

Table 6. Organic farmers' experience on advantages of organic farming.

	Madhya Pradesh ($N = 39$)	Tamil Nadu ($N = 40$)	Uttarakhand ($N = 40$)
Improve soil fertility	2.79 (1)	2.75 (1)	1.32 (3)
Environmental benefits	2.00 (3)	0.62	0.60
Avoid chemicals	0.20	2.67 (2)	2.07 (2)
Health benefits	2.15 (2)	1.42 (4)	3.07 (1)
Reduce input cost	0.82	1.92 (3)	1.20
Higher price	1.02 (4)	0.35	0
Higher yield	0.18	0.25	1.22 (4)
Secure market	0.54	0	0.1

Values in ( ) are rank.

Table 7. Organic farmers' experience on challenges encountered in organic farming.

	Madhya Pradesh ($N = 39$)	Tamil Nadu ($N = 40$)	Uttarakhand ($N = 40$)
Do not have enough manure	0.28	2.5 (2)	3.5 (1)
Insect and disease control	3.00 (1)	1.12 (4)	2.75 (2)
Weed control	0.13	0.7	1.45 (3)
Lack of labor	2.61 (2)	1.9 (3)	0.32
Low yield	0.87 (3)	2.55 (1)	0.60 (4)
Problem with price	0.35 (4)	1.12 (4)	0.52

Values in ( ) are rank.

farmers' age in Madhya Pradesh, where younger farmers responded more willingly to these types of questions.

Ranking advantages in practicing organic farming

Organic farmers had positive thoughts about improvement in soil fertility and health benefits as they ranked these factors among the advantages, although they were not tested. The farmers ranked improved soil fertility as the largest advantage of farming organically in two of three states, and as the third-largest advantage in Uttarakhand (Table 6). Health benefits ranked as number 1, 2 and 4 in Uttarakhand, Madhya Pradesh and Tamil Nadu, respectively. The avoidance of chemicals ranked as number 2 of the advantages of farming organically in two states. Only in Tamil Nadu did reduced input costs rank among the four most important advantages. Interestingly, the farmers in Uttarakhand ranked increased yield, which was not the case in the other two states. The price premium and market access did not figure among the top four advantages in Tamil Nadu and Uttarakhand. It is clear that organic farmers had a problem with market access for crops other than cotton in Madhya Pradesh with price premium listed as number 4 advantage. However, these two factors not having been listed in the other two states is understandable.

Challenges encountered in organic farming

The ranking of the challenges in organic farming were different and specific to case area (Table 7). Low yield was perceived as the biggest challenge in Tamil Nadu (high-input farms and also most of the farms were in the conversion period), but ranked lower in the other two states. Control of pests and diseases ranked number 1 as a challenge in Madhya Pradesh. Cotton is cultivated on only 4% of the farmed area but consumes more than 50% of pesticides in India. Hence, this factor is a real challenge for organic cotton producers. It was the second-largest challenge for Uttarakhand farmers. Lack of manure was a particular challenge in Tamil Nadu and Uttarakhand, whereas lack of labor was a particular issue in Madhya Pradesh and Tamil Nadu. Lack of manure was not a major challenge in Madhya Pradesh due to organic inputs being supplied by BioRe. In Uttarakhand, most of the farmers in hilly areas practiced mixed cropping. Hence, access to manure and control of weeds and pests in mixed cropping figured as major challenges. Interestingly, the weed control issue did not figure as a major challenge among the organic farmers of Tamil Nadu and Madhya Pradesh.

Discussion

Barriers to conversion for conventional farmers

This study showed that across these three states and settings, the inclination to convert was not influenced by the age and educational status of the farmer. This result differs from others studies where particularly the young and better educated farmers converted to organic farming[28–33]. Instead, production issues were the most prominent reason, although the high level of 'do not know' responses also indicates a lack of knowledge and understanding about

organic farming in all three case areas, although with variations between areas. Open-ended questions about barriers showed that farmers in all three case areas were more concerned about production barriers than market or institutional barriers, which is consistent with other studies[16,21,34–39]. Therefore, this study suggested that farmer age and education were not the determining factor for not converting, but rather a lack of understanding and fears about low yield were the major concerns. Hence, farmers need strong institutional support and an assured price premium with market access to offset the production barriers such as yield reduction.

Organic farmers

The difference in the reasons for and experiences with organic farming in the case areas probably has a regional background, such as farming systems and institutional support. There was a higher response from organic farmers than from conventional farmers even for the open-ended questions, which might be due to increased knowledge and awareness after conversion. However, there are differences in responses between the case areas among the organic farmers. The higher response from Tamil Nadu organic farmers might be due to the fact that they are in the conversion period and hence keenly observe the variables and find it easy to answer compared to the other two states. The lower percentage of poorly educated farmers in addition to strong NGOs support may be the other reason for the higher response from Tamil Nadu. The low response from Uttarakhand organic farmers might be because the conversion has had little impact on the low-input farms.

This study showed that when external support is available (market, technical and institutional), some farmers were motivated to improve the production, environment and health factors in all three case areas. Overall, in all the three cases, a reduction in input cost, improved soil fertility and health benefits were the main reasons for converting to organic farming. Similar results have also been reported in other studies[31,32,35,40–44]. Nevertheless, a substantial number of farmers were motivated by the price premium for certified organic cotton in Madhya Pradesh and few farmers in the other two states.

There is a difference between acceptance and ranking of the benefits of organic farming. In Tamil Nadu, input cost reduction ranked lower than expected, although 95% of the farmers accepted a cost reduction. Similarly, in Madhya Pradesh, the majority of the farmers accepted a cost reduction and actually incurred only one-third of the conventional cost[27] and still they ranked this lower as an advantage. This could be because organic farmers had to rely on biodynamic inputs and bio-pesticides from BioRe in Madhya Pradesh and organic inputs from the NGO in Tamil Nadu. In Uttarakhand, input cost reduction, the second top most motivating factor for conversion, was not ranked in the major advantages. This is understandable since most of the farms were under a low-input management system and spent less on input compared to the other two states[27].

The relative yields in organic farming are directly related to the intensity of prevailing farming systems and the level of external input before conversion[45]. Our findings regarding the yield aspects in low-input farms in the studied areas of Uttarakhand and high-input farms in Tamil Nadu were, in general, in agreement with the above statement. In Uttarakhand, some organic farms experienced yield increases. Higher yields of rice and millet were noticed in organic farming in Uttarakhand[12]. In Madhya Pradesh, the yield reduction was of less concern to organic farmers who were compensated through input cost reduction and a higher price premium. However, a substantial number of farmers observed yield increases after 4 years of conversion. Other studies reported up to 20% higher cotton yields[23,46,47]. The yield issue in Tamil Nadu is very clear, indicating that conversion of high-input farms resulted in a yield reduction during the conversion period, with organic rice yield merely 80% of the conventional rice yield in Tamil Nadu[27]. In Karnataka, the neighboring state to Tamil Nadu, rice yield was 21% lower in the first year of conversion (as also found in our study) and 22% higher in the organic over the conventional system after 4 years of conversion[12]. Thus, a yield increase is expected after 4 years of conversion, unlike in the developed world where organic yield is found to be lower even after the conversion period[48,49]. Interestingly, the low-input farms of Uttarakhand, also in the area of our study, experienced higher yields when adopting agro-ecological methods[27]. Studies from the USA also report that organic systems increase yield in drier areas[50,51]. Therefore, the low-input farms of Uttarakhand are highly suitable for large-scale conversion to organic agriculture.

Increased farm income by reducing the input cost and achieving a higher price premium is considered as the foremost advantage of organic farming in India[7,12]. However, in the present study, not all three case areas saw a significant improvement in the farm income. This could be because only cotton received a price premium and other rotational crops were sold at conventional price although a cost reduction was observed in Madhya Pradesh. In Uttarakhand, on the other hand, all the crops received a 10% price premium but there was not much of a cost reduction. In Tamil Nadu, an input cost reduction along with a 10% price premium to all crops resulted in an increase in income for 35% of the farms. This difference is due to some farms being in the post-conversion period (no yield reduction for 22% of the farms) and some farms in the conversion period where yield reduction was observed. However, the net margin was found to be non-significant between conventional and organic systems in all the three case areas[27]. Acknowledging that the farming systems, geographical characteristics and institutional settings vary by state, caution should be taken in generalizing these results to the whole of India. Moreover,

the conditions for organic farming vary for the different areas.

Conclusions and Implications

In this study, conventional producers identified production and marketing barriers as a constraint to adopting organic farming. Organic farmers were more concerned with health, environmental and production factors (such as pest control and lack of manure in all case areas, and low yield in Tamil Nadu) when institutional support is available. The study concludes that yield reduction and the issue of controlling pests and diseases without chemicals were considered as both a challenge for the organic farmers and a barrier for the conventional farmers. Mixed responses were obtained on yield aspects, with yields tending to decrease initially, and then to increase after the conversion period was completed. Yields increased on some farms in Uttarakhand and Madhya Pradesh because most of the farms there are in the post-conversion period, while Tamil Nadu farms found that yields had reduced, which is due to the farms being in the conversion period.

A balanced view on the disadvantages and benefits also needs to be presented and discussed in farmer communities. Indian farmers have a low level of technical knowledge about organic production methods unless supported by NGOs and private institutions, and thus marginal and small farmers need to acquire knowledge and training to practice organic farming. Private institutional support is available for specific crops to attract the lucrative organic export market, but farmers are lacking knowledge and in some cases inputs to grow the full range of rotational crops, that are imperative in a well-functioning organic production system. Thus, one of the biggest potentials lies in establishing organic markets for rotational crops and to provide institutional support, as was the case in Tamil Nadu. However, since this support was available only for a limited period due to the finiteness of the organic project fund, most of the conventional farmers were afraid to convert. Thus, it is important that a long-term strategy for the support is developed. Therefore, grassroots organizations, governments and research institutions need to cooperate in providing information, advice, training and financial support during the conversion period to marginal and small farmers for them to reap the benefits of organic farming.

Organic markets are expected to increase in India due to the driving demand for quality organic food by the rising income of middle classes. Therefore, marginal and small farmers should be encouraged to form organic farmers' associations, such as in the case area of Tamil Nadu, to facilitate the marketing of a variety of crops—organically certified or not—at the local market. This helps to increase farm profit and reduces the vulnerability of market access for specific certified organic products. Growing only specific crops for the organic export market is not advisable because it makes farms more vulnerable to the volatile export market and reduces farm biodiversity. Hence, a government scheme for compensating yield loss during the conversion period and the provision of a price premium for non-certified organic products would benefit the farmers and the environment. Subsidies for organic inputs, and supporting organic producers and organic consumer associations may be a viable option to increase the adoption of organic farming in India. Moreover, the diversion of public money from fertilizer subsidies alone to the development and use of agro-ecological cultivation methods, such as composting, legume seeds and biological pest management, should be considered.

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Book Review

The Conversion to Sustainable Agriculture: Principles, Processes, and Practices. By Steve Gliessman and Martha Rosemeyer (eds). 2009. CRC Press, Boca Raton, FL. 380 p., Hardback, $89.95, ISBN 9780849319174.

Is 'conversion to sustainable agriculture' a gradual process of change or a radical move from one point to another? Throughout the 15 chapters of this book, including conversion experiences in the USA, Canada, Latin America, Europe, the Middle East, Japan and Australia, the reader can conclude that 'conversion' is a gradual transition toward more resilient farming systems. This volume goes beyond the analysis of conversion at the on-farm level and attempts to provide guidelines for an analysis of conversion at the food-system scale. There is valuable material bringing to the surface the advances in the field, information on existing loopholes and ultimately inspiration for new inquiries. Common issues emerge although the experiences under review come from many different contexts. Interestingly, the authors share no common concept of sustainable agriculture and their diverse concepts are reflected in their use of different terminologies, which include ecological agriculture (European Union), ecological conservation agriculture (Japan), organic farming systems (USA) and agroecology (Cuba).

The three main themes of the book are presented in the first three chapters: Chapter 1: 'The framework for conversion' (S. Gliessman); Chapter 2: 'What do we know about the conversion process?' (M. Rosemeyer) and Chapter 3: 'The history of organic agriculture' (Jamilson and Perkins).

The framework for conversion that Gliessman elaborates in Chapter 1 builds on three steps proposed by Hill (1985)[1]: level 1 focuses on making conventional practices more efficient and less costly; level 2 on the substitution of conventional inputs and practices with alternative ones; level 3 on a redesign of the agroecosystem based on ecological processes and relationships. To this, Gliessman adds a fourth level, which focuses on the goal of re-establishing a culture of sustainability that takes into account the interactions among all components of the food system (p. 7). This fourth level attempts to make more explicit the critical mobilization of conventional structures of thinking, developing and practicing agriculture underneath each of the other levels.

Approaches to sustainable agriculture supposedly foster analysis based on integrative and holistic views to properly address complexity. However, the conversion framework presented is a linear trajectory of change, which facilitates the analysis of the parts but hinders a systemic analysis. Gliessman admits this defect when he says 'we know how to study the pieces of agroecosystems separately, but we are still limited in our ability to work with complexities of entire systems simultaneously' (p. 9). Why does linearity persist? Perhaps it is because the way the inquiries are designed is still very aligned to conventional scientific rational, or perhaps it is for the lack of sources and evidence to answer new questions.

In fact, in some of the cases presented in the book the linear view of the transition process only partially works. According to Chapter 6 'California, USA: The conversion of strawberry production' and Chapter 12 'Japan: Finding opportunities in the current crisis', the former practitioners of organic agriculture were small producers who had developed direct markets, a characteristic placed at level 4. As a corollary, we can say that in both the Californian and Japanese cases the move to organic impacted simultaneously the farm and the culture of sustainability, but this process cannot fit in a linear analysis. Once the certification process began to rule the practice of organic farming in both places, large agri-business entered the market causing an involution from level 4 to level 2 and the sticking of the conversion process at level 2.

Furthermore, since the framework was created from observing the transition from conventional modern agriculture to more ecological agriculture, it appears to be less useful for understanding the transition to sustainability from non-modern agriculture (e.g., peasant farming systems or mixes of traditional and modern agriculture). The two chapters treating the case of Mexico—Chapter 8 'Mexico: Perspectives on organic production' and Chapter 9 'Mexico: Traditional agriculture as a foundation for sustainability'—reveal the limitations of this framework when it comes to the peasant experience converting to sustainability. Since traditional agriculture has a remarkable ecological content, often without use of agrochemicals, levels 1 and 2 of the framework do not reflect the starting point of its transitions. Maria del Rocio Romero, Chapter 8's author, situates it in the fourth level, thus leaving a hole in our understanding of how this process began.

Very little seems to be known about what the transition from non-modern to sustainable agriculture means and implies. Following Rosemeyer's survey of what we know about the transition process in Chapter 2, we can conclude that research so far has stressed the process of transition from modern agriculture to organic farming systems. This might obscure that organic is only one of a set of agroecological options. Besides, it could cause a bias in the way research and resources on sustainable agriculture are

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oriented. In almost 30 years of research (this survey covers publications from 1980s up to the present), transitions from different systems other than modern do not appear to be important, but transitions from conventional to organic systems in both developed and developing countries do.

In Gliessman[2], we learned that traditional agricultural systems are an example of sustainability, as their agroecosystems are similar to the structure and function of the natural ecosystems of their biogeographic region. Indeed, characteristics of traditional agriculture have served as a basis for the development of sustainable systems, proof of which is seen in the transition experience of Cuba to agroecology, discussed in Chapter 10 'Cuba: A national-level experiment in conversion'.

If peasant-like traditional agriculture is ecologically sustainable, what should a transition from traditional to sustainable agriculture imply? Gonzalez Jacome (Chapter 9) raises the issue of modifying traditional agriculture to operate in better market conditions, while simultaneously reproducing its ecological knowledge foundations. In a world with 1.5 billion smallholders, many of them practicing traditional agriculture, we need to make more efforts to better understand what the transition from traditional agriculture to sustainability means. Koocheki, author of the chapter 'The Middle East: Adapting food production to local biophysical realities' raises concerns about this too, stating that prevailing models of sustainable agriculture may lack applicability in many developing countries.

Other important gaps in the research on conversions are acknowledged in the survey. For example, for a long time research on sustainable agriculture has been extremely oriented to the physical aspects of the farm during the transitional process, such as pest management, soil diseases, nutrient dynamics and soil nutrient availability. Certainly this is one type of knowledge needed for farmers to undertake the shift with confidence, but without integrating the social dimension, the understanding of conversion will not be fully accomplished. Interestingly, the issues on the economic and social dimensions in the recent literature are very similar to those mentioned in a 20-year-old article by MacRae et al.[3]. This might indicate that old issues remain unresolved.

A key tension in transition is certification, especially related to organic farming. While for some farmers organic certification works as a stimulus to finance the transition (by getting premium prices), for others it is a restriction or an unnecessary step. For example, small Japanese producers studied by Muramato, Hidaka and Mineta (Chapter 12), rejected the certification process, arguing they should not pay for a recognition they had achieved before the boom of organic certification. Dumaresque and Ecker, authors of Chapter 14 'Australia: Farmers responding to the need of conversion', take another angle on the issue through the story of the emergent 'middle way' agriculture in Australia. The term was coined to recognize the effort toward sustainability, '(...) which rejects the conventional model of agriculture and yet falls short of or rejects the organic agricultural model as well' (p. 324). Such an issue reveals the importance of diversifying formal approaches to recognize a wider range of sustainable options.

A common theme in most of the chapters deals with the influence of institutional change and human resource mobilization to enhance the process of conversion to sustainable agriculture. This was true for the conversion of conventional strawberry farms on the central coast of California, USA, where the role played by centers of research was clearly fundamental. In Chapter 7 'Ontario, Canada: Lessons in sustainability from organic farmers', institutional participation is a central piece of the authors' analysis. There, Clark and Sumner point out how institutional arrangements can also act as a barrier to sustainability. Similarly, the contributors of Chapter 11 'European Union: Key roles for institutional support' (G. Guzman and Antonio Alonso), center their analysis on how a system of subsidies allowed a quick move toward the redesign of the agroecosystem, because of tailored financial supports. These analyses allow seeing how both government and research institutions have the ability to influence the culture of sustainability. Therefore, institutions would better be considered as one of the cross-cutting issues of conversion.

Altogether, the book offers a big picture of the conversion to sustainability undertaken across the world. A chapter about China or India would have offered a more complete picture of the states of transition, since we know little of the extent to which their buoyant agricultural sectors are moving toward sustainability. The contributors are experts in the processes of sustainable agriculture of the regions and countries they examine. Without doubt, this is a 'must read' piece for scholars and students interested in understanding the multiple layers of conversion through a well-informed update on the evolution of sustainable agriculture.

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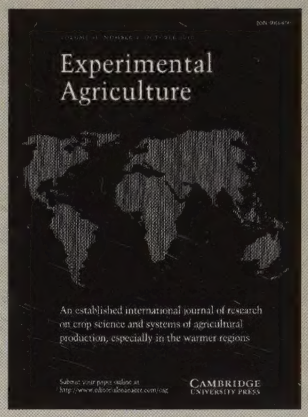
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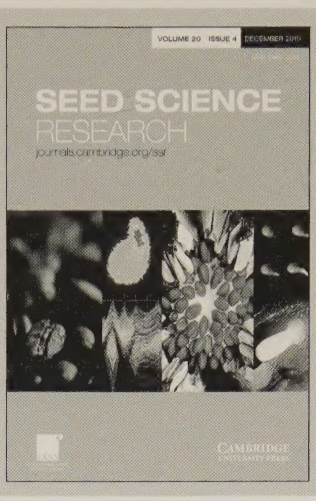

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